

How Is Meaning Grounded in the Organism?

Liz Stillwaggon Swan · Louis J. Goldberg

Received: 22 January 2010 / Accepted: 27 March 2010
© Springer Science+Business Media B.V. 2010

Abstract In this paper we address the interrelated questions of why and how certain features of an organism's environment become meaningful to it. We make the case that knowing the biology is essential to understanding the foundation of meaning-making in organisms. We employ Miguel Nicolelis et al's seminal research on the mammalian somatosensory system to enrich our own concept of *brain-objects* as the neurobiological intermediary between the environment and the consequent organismic behavior. In the final section, we explain how brain-objects advance the ongoing discussion of what constitutes a biosemiotic system. In general, this paper acknowledges Marcello Barbieri's call for biology to make room for meaning, and makes a contribution to that end.

Keywords Meaning · Brain-object · Nicolelis · Somatosensory system

The Biology of Meaning-Making in Organisms

In this paper, we propose a hypothesis that informs both the how and why of meaning-making in organisms. These questions—of how and why certain features in an organism's environment become meaningful to it—are interrelated in virtue of the fact that a comprehensive explanation of how meaning 'takes root' in the brain presupposes that certain features of the environment at least have the potential to become meaningful to the organism. The essential questions then are: which environmental features become

L. S. Swan (✉)

Boulder Evening Program, University of Colorado at Boulder, Boulder, CO 80309-0178, USA
e-mail: liz.swan@ucdenver.edu

L. J. Goldberg

Department of Oral Diagnostic Sciences, School of Dental Medicine, State University of New York at Buffalo, Buffalo, NY 14214, USA

L. J. Goldberg

New York State Center of Excellence in Bioinformatics & Life Sciences,
State University of New York at Buffalo, Buffalo, NY 14214, USA
e-mail: goldberg@buffalo.edu

meaningful to the organism and why? And can we provide a biological account of how these environmental features manage to ‘take root’ in the brain?

A different but related problem in cognitive science, known as the symbol-grounding problem,¹ asks whether and how the symbols used in a computer programming language could ever take on meaning for the computer in the same way that the letters and sentences comprising a human language are meaningful to its users. In the early days of Artificial Intelligence there was a lot of excitement over claims that computers were ‘learning’, ‘understanding’, and ‘reasoning’—psychological concepts usually reserved for human beings. Since that time, however, there has been a mounting suspicion (excepting, of course, among those devoted to ‘strong AI’²) that what computers are in fact doing is just, well, computing.

One way of putting the fundamental question of the symbol-grounding problem is to ask whether a computer or other artificially intelligent system recognizes that the words (or strings of symbols) in the phrase “strong coffee” *mean* strong coffee. Many are skeptical. As John Searle so compellingly demonstrated with his Chinese Room argument, there is no way to program meaning into a computational machine; or as he puts it, no amount of syntax will give you semantics (Searle 1980). As Searle explains, computers and robots can manipulate symbols (e.g., words, numbers, and images) in an intelligent-seeming manner and successfully complete the task at hand, but to ask what it all *means* to them is to pose an incoherent question.

We leave the symbol-grounding problem aside for now and turn to the question of how meaning is grounded in organic beings, like ourselves, where the fact that certain things are meaningful to us while others are not is taken for granted and the challenge is to explain how and why this is so.

As we see it, the question of how meaning is grounded in the organism is fundamentally a biological problem, but one that has implications for (at least) philosophy and psychology. Our reasoning is that a comprehensive account of meaning-making in organisms requires an explanation of how certain features of the environment influence the creation of *representations* of those features in the brain of the organism; and for this we need to understand the relevant neurobiology. But psychology and philosophy are also important aspects of a comprehensive account of meaning-making because what occurs in the neurobiology of the organism carries meaning for it insofar as it influences its behavior.

We do not have the problem, in this case, of figuring out how to force meaning into the system, as in the symbol-grounding problem. Rather, the challenge is one of explaining exactly how meaning emerges in the organism, between sensory stimuli and consequent behavior. On our account, there are three crucial components to the meaning-making process in organisms: 1) the environmental features that are salient to the organism for survival reasons; 2) the representations, within the organism’s brain, of those select features of the environment; and 3) the action taken by the organism which results from this entire process. Traditionally, accounts of meaning-making in philosophy and psychology have tended to leave out one of these three crucial components—environment, brain, or behavior. Our account, however,

¹ See Hamad 1990.

² See Searle 1980.

respects the need to ground the philosophical question of meaning-making within the foundation of biology because ultimately, anything that registers as meaningful in the human—and more broadly speaking, organismic—brain, must be so registered in the available neurobiological substrate.

Let us explain right up front why we believe knowing the biology is essential to understanding the process of meaning-making in organisms. Essentially, we see this approach as a corrective measure that responds to a long history in philosophy of mind of being squarely *off-topic*. We see it as an unfortunate irony that philosophy of *mind*, particularly in the second half of the 20th century (congruent with advances in computing) became so enamored with computer models of mind and artificial intelligence. While we acknowledge that computer and robot models of minds and agents, respectively, do inform to a certain extent particular philosophical questions about organic minds and agents, we have set for ourselves a different task in this paper. At the risk of being mistaken for pushing some new version of *élan vital*, we maintain that there is something categorically unique about the way organisms with sufficiently complex nervous systems interact with their worlds that has so far not been, and indeed may not ever be, duplicated artificially by machines.

But much more immediately to the point is this: we are not interested in questions of whether machine models can do what the organic mind does (e.g., understanding and learning) and to what extent. We are instead interested in the question of how organisms do what it is that we already know they do. We break with the tradition of comparing human minds to what they are *not*, and instead take a look at the mind for what it is; specifically, an extremely complex biological phenomenon that enables sufficiently complex organisms to make meaning out of their worlds. We know that animals, including us, navigate our respective environments with consistent adaptive success. How do we do it?

In what follows, we review a set of experiments conducted by Miguel Nicolelis et al on the rat somatosensory system, and outline some insights into organismic meaning-making that we believe are supported by the experiments. Next we introduce what we call *brain-objects* and explain their unique composition, and their role as the neurobiological intermediary between incoming sensory information and consequent organismic behavior. We conclude the paper with an explanation of how brain-objects advance the ongoing discussion in the field of Biosemiotics of what constitutes a biosemiotic system.

Nicolelis' Experiments

The work of Nicolelis et al as presented in their 2006 Scientific American publication is useful for our purposes because it presents a summary of many years of experimentation in a format accessible to those with a minimal background in neuroscience. The article contains the essential elements of their most significant findings, and an account of how these findings contribute to the goal of what they call “cracking the neural code”.³ What is of interest to us in these experiments is the finding that in the awake, freely moving rat, a specific feature of the rat's

³ Those seeking a more technical account of the experiments should refer to Nicolelis' 2008 publication.

environment was found to be represented in the rat's somatosensory system by a short burst of activity occurring in a particular set of neurons. In Nicolelis' view, this feature of the environment was thereby *encoded* in the activity of these neurons. In our view, this finding provides an important insight into an essential first step in the process of how meaning is grounded in complex organisms.⁴ This short burst of somatosensory neuronal activity (approximately 40 ms in duration) is a spatiotemporal entity that has a specific correspondence to a salient feature of the rat's environment. We call this entity a *brain-object*. In order to fully appreciate the brain-object as a representation in the rat brain of a specific environmental feature we provide the following account of Nicolelis' experiments.

In an effort to crack the 'neural code', Nicolelis et al trained laboratory rats in a maze-like apparatus to press the food-delivering button that corresponded to the relative width of the chamber which varied in each successive trial by a few millimeters and was assessed by the rat's snout whiskers (see Fig. 1). With an accuracy rate of 90%, a well-trained rat could discriminate whether the aperture was wider or narrower than in the previous trial, and was able to choose the corresponding button accordingly within 0.2 s.

Figure 2 (below) shows a schematic of the experiment, which has four main components: 1) the environmental condition (aperture width); 2) the stimulus caused in the animal by the particular environmental condition which is different from the last; the rat is able to make very fine distinctions between varying stimuli; 3) the brain-object (discussed in detail in section "[Four significant features of brain-objects](#)"), understood as a set of neural activity patterns that represents a particular environmental condition; and 4) the ensuing action taken by the organism.

In order to receive the food reward, the rat chooses either the button on the left or the one on the right, depending on which particular brain-object forms as a result of its phenomenal experience with the variable aperture width in that particular trial. The width of the aperture has meaning for the rat in the sense that the rat is able to extract from the relative depression of its whiskers an assessment of a feature of its environment that leads it to undertake a meaningful action, one that contributes to its survivability. Because we are after a biological account of meaning, we need to know what role the rat-whisker somatosensory system plays in making that assessment.

The neurobiological structure in question is one of a series of nerve fiber tracks that lead from the periphery (the base of the whiskers in this case) to the sensory cortex. This can be seen in Fig. 3 in which the neuronal elements of the pathway are shown in relation to the structure of the rat head and brain.

The Labeled-Line Model

Nicolelis explains that three decades prior to the 2006 paper, "the theory favored by most neuroscientists was known as the labeled-line model because it proposed that

⁴ We acknowledge Barbieri's prescription for understanding meaning from the ground up, i.e., from molecules to animals, and in fact see the current paper as following from and building on the foundation we developed in our 2010 publication in this same journal on symbolic communication in the molecular realm (see Stillwaggon and Goldberg 2010).

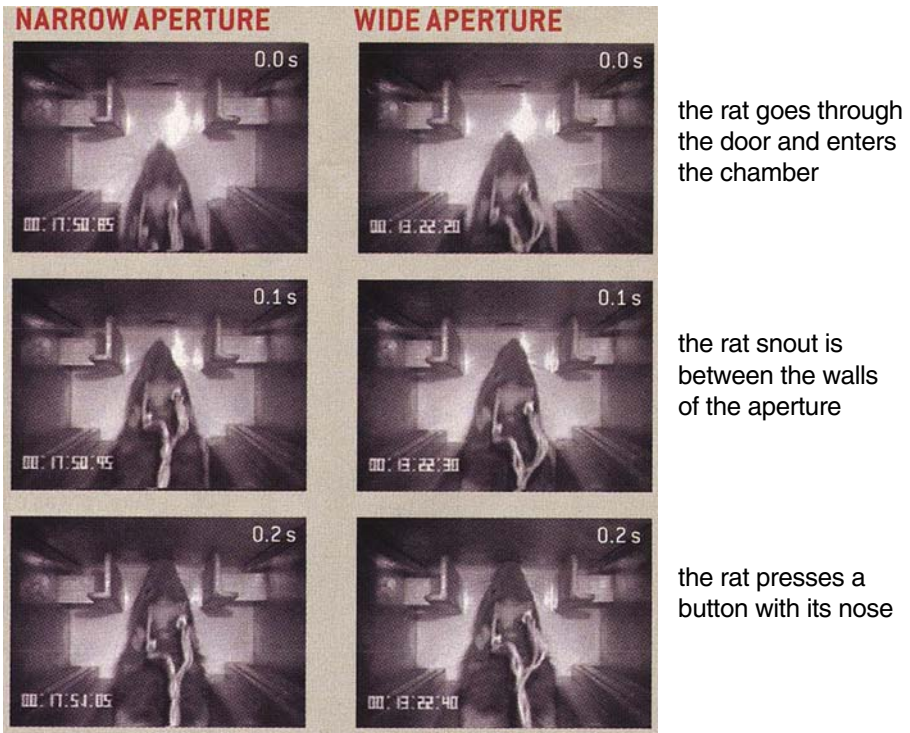


Fig. 1 A rat in Nicolelis’ experimental apparatus: 1) starting from the top at 0.0. s, rat enters dark chamber; 2) at 0.1 s, using whiskers, rat assesses aperture width (which varies by a few mm each trial); 3) at 0.2 s, rat chooses correct, food-delivering button with 90% accuracy (modified from Nicolelis and Ribeiro)

sensory information generated at the body’s periphery is conveyed through multiple parallel neural pathways all the way to the brain’s neocortex” (Nicolelis and Ribeiro 2006). In the rat-whisker case, the model described 52 parallel pathways, 26 per side, running from each whisker to the primary somatosensory (S1) cortex of the rat brain.

environmental condition	stimulus	representation	animal response
aperture width	whisker deformation	neural activity pattern	move to wall
narrow	more	pattern for narrow	press on left
wide	less	pattern for wide	press on right

Fig. 2 Schematic of Nicolelis rat-whisker experiments

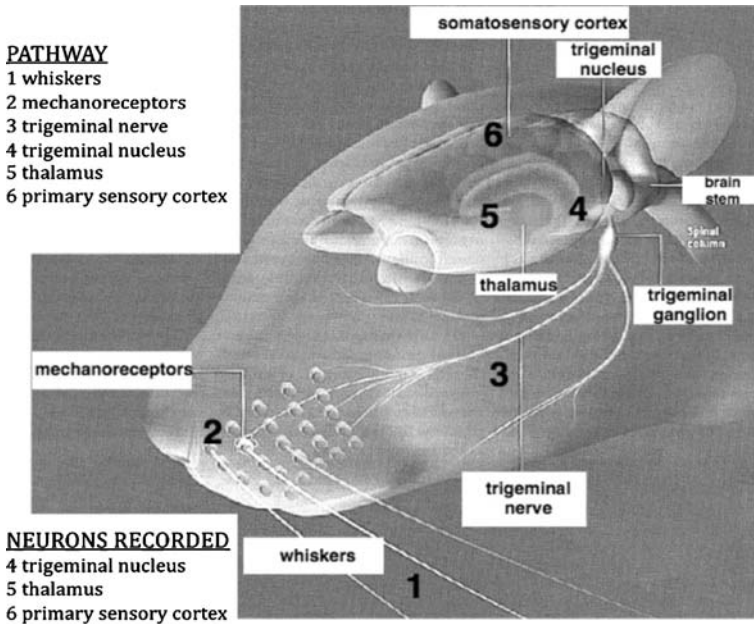


Fig. 3 A drawing of the rat head with superimposed brain structures of the rat-whisker somatosensory system. Structures of interest are numbered: 1) whiskers; 2) mechanoreceptors; 3) primary afferent fibers connecting the mechanoreceptors to neurons in 4; 4) the trigeminal sensory nucleus; 5) a nucleus in the thalamus whose neurons receive input from neurons in the trigeminal sensory nucleus; 6) the primary sensory cortex, neurons which receive input from the neurons in the thalamus (drawing of rat head is modified from Nicoletis and Ribeiro 2006)

What travels over the pathway (shown in Fig. 3 above) is a wave of electrochemical excitation that moves from receptor to cortex. Experiments with anesthetized animals indicated that each whisker had its own specific pathway to the cortex that was distinct from the other whisker pathways. This observation led to the conclusion that the somatosensory system was merely a conduit that carried the effects of whisker stimulation from periphery to cortex. The significant aspect of the system's architecture was believed to reside in the maintenance of the spatial integrity of the distribution of the whiskers on the face throughout the entire somatosensory system up to and including the cortex. It was thought that maintaining the discreteness of the individual pathways demonstrated the validity of that claim and was somehow necessary for the brain's interpretation of whisker stimulation. An illustration to show the elements of the labeled-line theory for the rat-whisker somatosensory system is shown in Fig. 4.

Nicoletis notes that anatomical and physiological studies in the 1970s and early 1980s revealed that, similar to the cortex, there were “topographic maps in subcortical structures, including the brain stem and thalamus, where the clusters were dubbed barrelets and barreloids. Indeed, stacks of these topographic maps at each of the subcortical relays of the trigeminal system were shown by subsequent investigators to link the peripheral sensory receptors in the facial whiskers of rats all the way up to the S1 cortex” (ibid).

This view emphasized the structural coherence of the pathways—how structure at the periphery (organization of the whiskers) is maintained in the structure of the

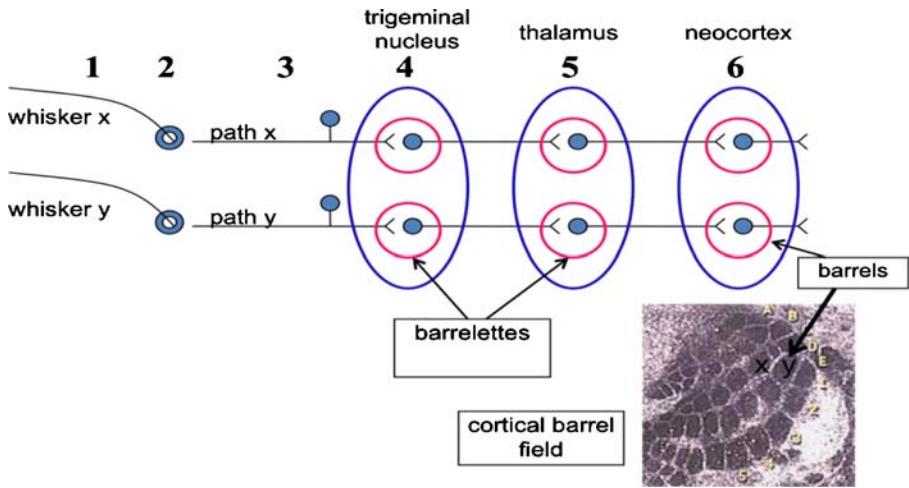


Fig. 4 An illustration of the labeled-line model. Components of two distinct parallel pathways (path x and path y) leading from two whiskers to the primary somatosensory cortex are shown. The numbers correspond to those shown in Fig. 3 and indicate anatomical structures that are the fundamental components of the rat-whisker somatosensory pathway. The photographic insert shows segmented groups (barrels) of heavily stained neurons on the surface of the rat somatosensory cortex

brain (organization of the cortex in barrels, and organization of the trigeminal nucleus and thalamus in barrelettes). Such a view is exemplary of the classical perspective of how brain anatomy constrains physiology, i.e., how structure determines function, and how form and function are integrated. The neurons in the pathway carry flow from whiskers along well-defined pathways from receptors to cortex.

The Demise of the Labeled-Line Model

The novelty of Nicolelis’ research in the rat somatosensory system is the ability to simultaneously record the activity of approximately 50 individual neurons in the somatosensory system of awake rats. In many of the previous studies on the rat-whisker somatosensory system, activation pathways of *single neurons in anesthetized animals* were tracked, which gave the false impression that the somatosensory system had a simple structure that supported simple, linear processes. Nicolelis’ methodological advancement gave rise to the insight that the pathways activated in awake organisms are far more complex than previously believed.

Nicolelis’ experiments showed that in awake and active rats, the pathways in the somatosensory system are not at all discrete. Many tens of thousands of synaptic connections that are dormant or silent in the anesthetized animal become active in the awake animal at every nuclear level (trigeminal, thalamus, and cortex). One of the most striking findings in these experiments was the observation that stimulation of a single whisker in the awake animal activates neurons across the whole field of somatosensory neurons, and the presumed strictly linear pathways are not evident. Nicolelis states that such stimulation of individual whiskers “reveals a complex

network of reactions distributed across populations of neurons and over time. Sensory information of a single whisker is thus encoded in the spatiotemporal pattern of responses by a multitude of cells throughout the animal's trigeminal system" (ibid).

In his view these results were "clear" and "shocking" (ibid). They demonstrated the unexpected finding that "single whisker deflections in awake animals triggered complex waves of electrical activity that spread across multiple barrel-shaped clusters within each of the neural structures along the trigeminal system" (ibid). He stated that these results were not consistent with the labeled-line model and proposed in its stead "an alternative model known as a distributed representation or a population neural code" (ibid).

The Alternative Model and Width Detection in the Maze

With this new understanding of the effects of whisker movements on neurons in the somatosensory system we return to the behavior of rats in the apparatus. In the experimental apparatus many of the rat's whiskers come in contact with the aperture walls. This results in what Nicolelis calls "storms of electrical impulses sweeping through the central nervous system" (ibid). He goes on to say that these storms "somehow translate into thoughts, emotions and sensations" (ibid)—in other words, into *meaning*. This chaotic-seeming electrical storm provides the foundation for the emergence of the ability in complex animals to make consistent, fine, and rapid discriminations of significant features of their environments. Nicolelis' experiments provide a neurobiological model of how these "storms of electrical impulses" in the brain ground the ongoing, survival-enhancing, fine and rapid discriminations of dynamic features of the environment.

While the rats were negotiating the maze, recordings were being made from up to 50 neurons in the three nuclei in the trigeminal somatosensory system. When the "spatiotemporal firing patterns of neuron populations recorded during the execution of this task" were fed into an artificial neural network (ANN), "the ANN could predict with great accuracy whether the rats were going to correctly identify a wide versus a narrow aperture on any given try" (Nicolelis and Ribeiro 2006). For Nicolelis this was a demonstration that the activity patterns of sets of neurons in the somatosensory system "encoded information" concerning the specific aperture width of particular trials.

While the flow of activity involved in the detection of aperture width still basically moves from the periphery to the cortex, the focus is no longer on the parallel fiber tracts of the labeled-line model but on the activity patterns in the cell bodies of neurons in each of the three nuclei in the system—the trigeminal, thalamic, and cortical. In the trigeminal sensory system of awake animals what now appears to exist is a large, open field of tens of thousands of somatosensory system neurons, many of which are potentially interconnected. We hypothesize that there comes into existence, out of this field of neurons, what we are calling brain-objects—in this particular case, unique sets of neurons that represent aperture width in the Nicolelis maze experiments. The model of the representation of features of the environment now moves to what Nicolelis calls a "distributed representation or a population neural code" (ibid.).

A Model of Brain-Objects in the Rat-Whisker Case

Figure 5 is a diagrammatic illustration of neurons (open round circles in Fig. 5a) located in the nuclei (trigeminal, thalamic, primary cortex) of the trigeminal somatosensory system. There are thousands of such neurons and they are interconnected in each nuclei by a dense meshwork of what Edelman calls “overlapping dendritic and axonal arbors” (Edelman 1987). When a whisker or sensory nerve from a whisker is stimulated in the anesthetized animal the only neurons activated are those located in the barreletes, barreloids and barrels as shown in Fig. 4. In Fig. 5, this direct pathway is represented by the solid lines. The interconnections across whisker domains are dormant. The fine axon collateral arborizations that cross barrel domains cannot be activated.

In the awake animal, Nicolelis demonstrated that these interconnections are open and therefore stimulation from a whisker spreads across a wide area of the trigeminal somatosensory system to potentially activate many neurons. The neurons in the awake animal are now part of what Nicolelis calls, “multiple interconnected brain structures, forming a vast neural circuit known as the somatosensory system”. It is Nicolelis’ view, that the capacity of the mammalian brain to form such “vast neural circuits” is what accounts for “the broad repertoire of tactile sensations” (Nicolelis and Ribeiro 2006) available to mammals such as the rat.

Figure 5B is an illustration of what hypothetically occurs in the rat-whisker somatosensory system during Nicolelis’ experiments with the wide and narrow apertures. In the course of learning the meaning of the two conditions (meaning in the context of recognizing that each aperture dimension requires a certain specific behavior to receive a food reward), the rat is placed in the apparatus numerous times. After many trials the rat learns the significance of the different aperture widths and

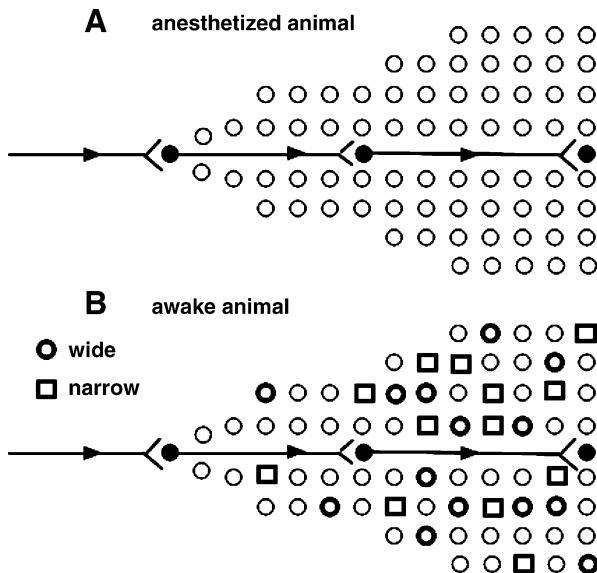


Fig. 5 A diagrammatic illustration of brain-objects

the related adaptive action that leads to a reward. On Edelman's account, this would be an example of neuronal group selection where, from a network of interconnected individual neurons, there is selected a neuronal group that will consistently be activated by a stable environmental stimulus that has adaptive value.

Two neuronal groups are shown in Fig. 5b. The bold round neurons form the neuronal group activated by the wide-aperture signal, and the bold square neurons form the neuronal group activated by the narrow-aperture signal. For Edelman these neurons are dynamically selected through a process of "modification of the strengths of synaptic connections" (Edelman 1987) until the strengths are enhanced for the formation of each neuronal group.

Four Significant Features of Brain-Objects

In this section, we discuss the significant features in our account of brain-objects; specifically: a) they are neurobiological phenomena by which subsets of neurons in the somatosensory system come to represent particular features of the world; b) they are real, spatio-temporal entities; c) they are extremely short-lived phenomena and yet are necessary for the initiation and successful performance of the consequent motor act; d) they are the foundational neurobiological units of meaning for the organism.

- a) **Brain-objects are the mechanism by which features of the world become features of the brain.** The first step in any feature of the environment's becoming known to, and thus having meaning for, the organism is for it to be represented in the brain. In the rat-whisker feature detection example under consideration here, this representation is made manifest in the formation of brain-objects in the rat trigeminal somatosensory system. The brain-object stands for the feature and will be evaluated, and acted upon, by other parts of the brain. Brain-objects permit the highly evolved mammalian nervous system to represent, within the organism, in increasingly finer and richer detail, features of the environment that are crucial for its survival. Many of the neurons in the rat somatosensory system are part of a network—this means they have the *potential* to become fully interconnected—but, crucially, only the set of neurons activated by the stimulus is what we are calling the brain-object. This particular set comes into being by repetition of the stimulus and by the significance of the stimulus to the organism. The rat (and human) somatosensory system has the potential for producing an essentially infinite number of brain-objects.
- b) **Brain-objects are real things, with spatial and temporal dimensions.** Our term 'brain-object' employs an unorthodox usage of the word 'object' that we believe is justified because it refers to a real, physical, and repeatable set of neural activity patterns whose collective existence, however brief, is sufficiently meaningful to direct the organism's action in the world. Just as objects in the environment are structured in a certain shape with certain dimensions, so are brain-objects physical things that have physical effects in the world. In essence, the physicality of brain-objects is borne out by their causal efficacy. The crucial insight here is this: *the spatial dimensions of the brain-object are determined by*

the spatial locations of those neurons within the rat-whisker somatosensory system that respond to a particular degree of whisker bending which is in turn determined by the distance between the walls.

In essence, there is a direct correspondence, an isomorphism really, between the ‘objectness’ (spaciality and temporality) of the environmental stimulus and the resulting brain-object that represents it. The three-dimensional distribution of the set of participatory neurons within the somatosensory system is the *spatial* component of the brain-object. And the brief flurry of activity in those neurons produced by the stimulus is the *temporal* component of the brain-object. Together they form the entity that represents, in the neurobiological substrate, an important feature of the rat’s environment, namely aperture width. In summary, the line we are drawing—one we believe begins to demystify how meaning emerges in the organism—is a direct one from the environment, through the organism, and back out into the environment in the form of meaningful action taken by the organism.

- c) **Brain-objects have an extremely short existence yet are necessary to direct action.** Representations of things in our environment must endure long enough to have meaning for us, yet must extinguish quickly enough to be adaptive—adaptive in the sense that the system is almost immediately cleared and ready to receive and represent the next signal. The brain-object has meaning for the rat navigating the apparatus; we know this in virtue of the fact that the rat consistently chooses the correct (i.e., food-delivering) button. This extremely fast brain-object formation capability of the rat (and more generally, of all mammals) accounts for the apparent immediate, transparent links between the rat’s contact with its environment, the representation of that contact which captures the salient features of its environment, and its consequent adaptive responses—all of which takes place in 0.2 s.

In the rat case, the brain-object comes into being when its whiskers are bent by the chamber walls. There occurs, approximately 10 ms after the whisker bending, a period of electrochemical activity in a set of neurons distributed across the entire rat-whisker somatosensory system that lasts for approximately 50 ms. Objectively speaking, this activity demonstrates the electrochemical flow along neurons and fibers in the somatosensory system that proceeds from the periphery to the cortex. But on our account, it demonstrates the very brief existence of a brain-object composed of a particular set of neurons and the process of electrochemical activity these neurons support.

Nicolelis’ experiments show us that the somatosensory system has the extraordinary capacity to represent in its neurobiological substrate an essentially infinite variety of subtle aspects of the environment. It does this by the creation of brain-objects out of a field of thousands of neurons, as described above. Once established, these brain-objects are ephemeral in the sense that they only come into existence when the appropriate stimulus is presented, and they exist in the somatosensory system, each time the stimulus is presented, for only approximately 50 ms. If the stimulus is not repetitively presented, or does not retain its adaptive significance to the organism, the pathway will decay and the brain object will not come into existence anymore. In this case, if trained rats are not placed in the apparatus for a considerable period of time the behavior will

extinguish, and the same will occur if no food is delivered when the rat presses the correct button. The width of the apparatus will be a stimulus of no significance to the rat and the button-pressing behavior will not be elicited.

As noted above, Nicolelis fed the output activity of a set of neurons into an artificial neural network and demonstrated that the activity of the set of neurons activated by whisker stimulation of a particular width were predictive of the correct choice. This provides direct evidence that what we are calling the brain-object carries with it information which is used by the rat to produce adaptive behaviors. Nicolelis states this point as follows:

Our ability to predict the animal's behavior from neural firing patterns alone suggested that we were on the right track toward learning to interpret the language of the nervous system. It [is] already abundantly clear that instead of relying solely on the activity of specialized individual neurons or even linear columns of barrel-shaped modules, the mammalian brain more likely depends on highly distributed neural ensembles, dynamically formed by broadly tuned cells, to endow animals with their exquisite perceptual capabilities (ibid).

- d) **Brain-objects are the mechanism by which meaning is grounded in the organism.** We believe Nicolelis' research supports the notion that mind-world correlations do not happen in a void, but in a biological precondition of organism-environment interaction that is and has been the necessary grounding for all possible experience since the origin of the particular organism as well as its species. The animal moves in a head first direction through space, scanning the environment as it goes. As it moves forward the representations of the environment move back through it from sensors, to brain-objects, to analysis systems, to motor systems. We see evolution in action as the environment moves through the organism and the organism moves through the environment, reacting, adapting, and surviving, just as entire species do on the grand scale. This insight begins to demystify the philosophical problem of how meaning gets 'in the head'.

A likely objection that might arise at this point to the account we are developing would be, do you really want to claim that the button on the left (or right) *means* something to the rat? Can we really talk about rats as having *meaningful* experience of their world? To which we reply, yes, on both counts. As Barbieri has so compellingly argued, biology has to make room for meaning (Barbieri 2008a, b) and a naturalistic account such as the one developed in this paper begins to do just that. Meaning is not limited to the human realm; meaning also manifests in organisms that continuously act in ways that ensure and prolong their survival in the world.

We can contextualize our argument for meaning-making in organisms within Barbieri's account of "organic meaning", which he describes as a "link between two organic worlds" that requires highly specialized recognition interlocutors (ibid). The Nicolelis experiments provide a microcosm wherein the external organic world of the experimental apparatus is linked to the internal organic world of the rat's somatosensory system, and the two are linked by what we are calling brain-objects which act as the specialized interlocutors between the two organic worlds. These

brain-objects are in turn interpreted by processing centers in the brain that direct the organism's survival-enhancing action.

But can this very specific experimental model be extrapolated to organismic meaning-making in general? Yes it can, since we argue that Nicolelis' experiments provide a model of what happens all the time in all organisms with complex nervous systems. In essence, the brain-objects that emerge from the ongoing interaction between animal and world serve as neurobiological intermediaries that are then interpreted by higher processing centers of the brain that direct the animal's behavior in the world. Because brain-objects serve as the bridge, the interlocutors, between inner and outer worlds of the organism-environment system, they are the fundamental components of organic meaning.

Close Relatives of Brain-Objects

In this section, we take a look at two theoretically close relatives to what we are calling 'brain-objects'. The first is a historical example, namely William James' theory of *chreods*. The second is a contemporary example, namely Gerald Edelman's Theory of Neuronal Group Selection. Since, in addition to the work of Nicolelis, we draw inspiration from these two sources for our theory of brain-objects, some discussion of each is in order.

William James' *chreods*

William James chose the term *chreod* to designate useful and well-worn neural pathways found in actional, mental, and symbolic behavioral operations (James 1911). These neural tracks, for James, are associated with goal-oriented behavioral tendencies that are played out in concrete circumstances. The neural pathways are established by the organism's repeatedly receiving a certain stimulus. If the stimulus remains about the same in location and intensity, if it is repeated often enough, and if it requires a survival-enhancing response by the organism, then a *chreod* will be established in the neurobiological substrate.

Ralph Pred explains, "The term 'chreod' is used to emphasize the goal-oriented nature and the experiential constituents of neural-pathway facilitated habitual actions as they unfold, especially in flows coordinating perception and action in personal activity-situations. Chreods range upwards in complexity from those drawing on simple movements to those involving combined movements or sequences of sensory-action loops linked in flexible action routines, readily invocable in situation-specific service to prior intentions" (Pred 2005). It is our view that Nicolelis' experiments show the actual creation of such pathways in the neurobiological substrate of the mammalian somatosensory system.

We add to James' view of neural pathway formation, the notion that out of these pathways the creation of brain-objects emerges as the essential element in the transfer of the salience of features in the environment to the brain. This view is compatible with Nicolelis' use of the terms 'neural ensemble' and 'neural assembly' (ibid) to describe this phenomenon; for example, Nicolelis explains, "A single neuron's membership in those ensembles is probably fluid and might change from

moment to moment, and one neuron can participate in many of these assemblies simultaneously” (ibid). We employ the term ‘brain-object’ mainly to emphasize a new desideratum—that of understanding this phenomenon as a necessary precursor to meaning in organismic cognition and action.

Gerald Edelman’s *Theory of Neuronal Group Selection*

Nicolelis believed that the results of his experiments demonstrated that the ability of a rat to extract “fine and meaningful tactile information” from its environment was dependent upon a model of neuronal activity that he identified as “a distributed representation or a population neural code” (Nicolelis and Ribeiro 2006). This model involves “combining the activity of large populations of single neurons” in the formation of “neural ensembles” (ibid). He reasoned that “the collective interactions of neurons” permits the formation of neural ensembles and such ensembles have the capability of yielding “exquisitely accurate descriptions of our surrounding environment” (ibid).

In his book, “Neural Darwinism,” Gerald Edelman gives an extensive elaboration of a population model of neuronal activity that he called the Theory of Neuronal Group Selection. He believed that ensembles of neurons, or what he termed neuronal groups, were “dynamically” selected from large networks of neurons. According to Edelman, successful selection of a neuronal group from tens of thousands of neurons in a network is dependent upon altering the synaptic efficacies among neurons in the network “so that there is an increased probability of their response to similar or identical signals”. When “similar or identical signals” are presented frequently at the same location “dynamically selected neuronal groups are established”. In this view, neuronal groups are formed “through epigenetic modifications in the strength of synaptic connections” among neurons in the network. These selected neuronal groups are composed of “collections of hundreds to thousands of strongly interconnected neurons” which act as “functional units.” These functional units are “correlated with various signals” from the environment. These collections of strongly connected neurons which are correlated with persistent and stable environmental signals are what we are calling brain-objects. Edelman believes that such neuronal structures serve “the hedonic or value-ridden aspects of behavior” (Edelman 1987). In other words, neuronal groups, or brain-objects, formed by significant features of the animal’s environment lead to behaviors that are adaptive for the organism.

Brain-Objects and Semiotic Systems

In Barbieri’s “Is the Cell A Semiotic System?” (Barbieri 2008b) he presents the three classic models of semiotic systems. The first, proposed by Ferdinand de Saussure and later expanded by Marcel Florkin, is a duality of *signifier* and *signified*—e.g., genotype and phenotype. The second model, proposed by Charles Sanders Peirce, and later endorsed by Thomas Sebeok, is a trinity of *signifier*, *signified*, and *interpreter*—wherein there is an interpreter between genotype and phenotype. The third model, proposed by Barbieri, is also a trinity but one that relies on a codemaker instead of an interpreter; thus its three essential components are: *sign*, *meaning* and *code*—or genotype, phenotype, and codemaker. Barbieri’s account has intuitive

appeal at least in the context of the genetic code since this code works independently of an interpreter; the processes linking genotype and phenotype are executed rather than interpreted.

In this paper we have focused not on individual cells, but rather populations of large ensembles or groups of highly specialized nerve cells in the mammalian somatosensory system. But since we know complex organisms with nervous systems are semiotic systems, this difference in scale does not pose much of a problem, but rather an invitation to further discussion regarding whether some components of the brain, the entire nervous system, or the active organism in its environment is properly designated as the semiotic system; with the likely possibility of conceiving of each as an interdependent semiotic system embedded in all the rest, which is fundamentally how nature works—systems within systems.

Barbieri describes a semiotic system as made of “two distinct worlds: a world of objects that we call *signs* and a world of objects that represent their *meaning*” (Barbieri 2008b). So where do brain-objects fit in this schema? We have defined brain-objects as the neurobiological intermediary between sensory stimuli and consequent behavior. Thus brain-objects are what Barbieri refers to as those objects that represent the *meaning* of external signs to the organism. And thus the semiotic system on our account is identified as the whole system of organism-in-environment⁵ with brain-objects acting as the semiotic intermediaries between the organic world within and the organic world without. And therefore we have an account of at least the fundamentals of biological meaning-making in organisms.

Barbieri’s definition of a semiotic system as being a trinity of sign, meaning, and code, is instructive in understanding what Nicolelis was after in his attempt to “crack the neural code” (Nicolelis and Ribeiro 2006). Nicolelis is essentially trying to understand how the organismic brain *encodes* features of the environment for survival purposes. In essence, Nicolelis asks what role the rat’s brain plays in coordinating the rat’s swift and masterful negotiation of its environment. The consistent patterns of neural activity that he discovered, and which we are calling brain-objects, fulfill the role of a code that serves to link signs from the external world to meaning in the organism’s inner world. The codemaker on this account is the organismic brain which provides an essentially limitless set of possibilities for representing environmental features via distinct and consistent patterns of activity, i.e., the brain-objects. We leave for the next stage of our research a more comprehensive account of how our notion of brain-objects can be understood as providing a neurobiological basis for extending Barbieri’s program to the context of human biosemiosis.

References

- Barbieri, M. (2008a). Has biosemiotics come of age? And postscript. In M. Barbieri (Ed.), *Introduction to biosemiotics* (pp. 101–113). The Netherlands: Springer.

⁵ Though, strictly speaking, our account suggests that the semiotic system on offer would be *brain-environment*, we recognize the limitations of the eliminative materialist approach in philosophy, according to which the mind is *just the brain*, and instead acknowledge the obvious: that brains are not independent entities, but necessarily dependent on host bodies embedded in host environments.

- Barbieri, M. (2008b). Is the cell a semiotic system? In M. Barbieri (Ed.), *Introduction to biosemiotics* (pp. 179–207). The Netherlands: Springer.
- Edelman, G. (1987). *Neural Darwinism: The theory of neuronal group selection*. New York: Basic Books.
- Harnad, S. (1990). The symbol grounding problem. In *Physica D*, 42, 335–346.
- James, W. (1911). *Some problems of philosophy: A beginning of an introduction to philosophy*. New York: Longmans, Green, and Co.
- Nicolelis, M. (Ed.). (2008). *Methods for neural ensemble recordings* (2nd ed.). Boca Raton: CRC.
- Nicolelis, M., & Ribeiro, S. (2006). Seeking the neural code. In *Scientific American*, 295(6), 70–77.
- Pred, R. (2005). *Onflow: Dynamics of consciousness and experience*. Cambridge: MIT.
- Searle, J. (1980). Minds, brains, and programs. *Behavioral and Brain Sciences*, 3(3), 417–457.
- Stillwaggon Swan, L., & Goldberg, L. J. (2010). Biosymbols: symbols in life and mind. *Biosemiotics*, 3 (1), 17–31.