

A neurobiological interpretation of semiotics: meaning, representation, and information

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Abstract

The branch of semiotics called semantics deals with the relation between meanings and representations, widely known as the symbol grounding problem. The other branches of semiotics, syntactics which deals with symbol-symbol relations as in a dictionary, and pragmatics which deals with symbol-action paradigms as in traffic signs, are well done by computers, but semantics has eluded computer simulation. In my view, this is because computer programmers have neglected that aspect of Shannon's definition by which information has no meaning; computers process information, whereas brains create meaning. Brains obtain information about the world through the consequences of their own embodied actions. The information thus obtained is used in constructing meaning and is then discarded. One kind of information in the world consists of representations made by other brains for social communication. Computers use representations for information processing and symbol manipulation. However, brains have no internal representations. They deploy dynamic neural operators in the form of activity patterns, which constitute and implement meaning but not information, so that the problem of symbol grounding does not arise. Brains construct external representations in the form of material objects or movements as their means for expressing their internal states of meaning, such as words, books, paintings, and music, as well as facial expressions and gestures in animals and humans, but even though those material objects are made with the intent to elicit meaning in other brains, they have no meanings in themselves and do not carry meanings as if

they were buckets or placards. Meanings can only exist in brains, because each meaning expresses the entire history and experience of an individual. It is an activity pattern that occupies the entire available brain, constituting a location in the intentional structure of a brain. It is the limited sharing of meanings between brains for social purposes that requires reciprocal exchanges of representations, each presentation by a transmitting brain inducing the construction of new meaning in the receiving brain. EEG data indicate that neural patterns of meanings in each brain occur in trajectories of discrete steps, which are demarcated by first order state transitions that enable formation of spatiotemporal patterns of spatially coherent oscillations. Amplitude modulation is the mode of expressing meanings. These wave packets do not represent external objects; they embody and implement the meanings of objects for each individual, in terms of what they portend for the future of that individual, and what that individual should do with and about them.

Introduction

Archeologists studying a petroglyph ask not only who did it and when, but what does it mean? They conclude that no one can really know what it means now, and that they can only speculate on the prior meanings in the minds of the makers and viewers. The lesson is that the petroglyph contains no meaning, even though it was made by humans with the intent to communicate meaning by evoking the formation of comparable meanings in other humans.

Engineers who want to make semantic machines are faced with the task of defining

meaning, which at present exists only in brains, and then with the task of learning how to make or cause meaning in machines, as shown by Tani [1996], Hendriks-Jansen [1996], and Clark [1997]. Requirements of analog models to simulate the chaotic dynamics of brains include global albeit sparse connectivity, continuous time dynamics, and distributed spatial functions in two-dimensional arrays of nonlinear integrators [Eisenberg, Freeman and Burke, 1989]. Digital hardware may suffice to emulate the biological functions of sensory cortex in brains by use of nonlinear difference equations as in KIII sets [Chang and Freeman, 1996; Shimoide and Freeman, 1995; Freeman et al., 1996], provided that problems of numerical instabilities, attractor crowding, and lack of shadowing trajectories [Freeman et al. 1997; Chang and Freeman, 1998] can be solved. A next step to machine intelligence may be to use a KIII model of a sensory cortex as an interface between the unconstrained real world, which is infinitely complex and ultimately unknowable in complete detail, and the finite state automata that constitute the main support for contemporary artificial intelligence. This interface derived from brain dynamics may well provide an artificial eye, ear, and nose for conventional computers.

However, this step will require addressing a major problem: the semantic relation between representation and meaning in brain function. Because the Shannon-Weaver information theory divorces meaning from information, it cannot apply to brains. This brief essay aims to sketch some of the principal elements of the problem, as a basis for indicating some possible pathways toward solutions, which have been more fully developed elsewhere [Freeman, 1999, 2000]. These pathways offer new insights into the biological basis of meaning as relations between brain states and behavioral actions, not between symbols embedded within syntactical systems like encyclopedias.

Communication by representations

Operational discreteness is essential for communication in dialogue. A pair of brains can act, sense, and construct in alternation with respect to each other, not merely as dogs sniff, but as two humans speak, listen, and hear. Consider brains **A** and **B** interacting (Figure 1), where **A-B** are parent-child, wife-husband, rabbit-dog, philosopher-biologist, neuroscientist-rabbit, etc. **A** has a thought that constitutes some meaning $M(a)$. In accordance with this meaning, **A** acts to shape a bit of matter in the world (a trace of ink on paper, a vibration of air, a set of keystrokes on e-mail, movements of the face, limbs, etc.) to create a representation (a sign or symbol for humans but merely a sign for animals, in both cases, information) directed at **B**, $R(b,a)$. **B** is impacted by this shaped matter and is induced by thought to create a meaning $M(b)$. So **B** acts to shape a bit of matter in accordance with $M(b)$ in a representation $R(a,b)$, which impacts on **A** to induce $M(a+1)$.

And so on. Already by this description there is implicit recognition of a discrete ebb and flow of conversation like recurrence of tides, so that meanings, $M(i)$'s as constructions of thoughts, become the internal active states, and the $R(i,j)$'s as forms of matter and energy become the external representations. By its material nature an external "re-presentation" can be used over and over. It cannot be said to contain or carry meaning, since the meanings are located uniquely inside **A** and **B** and not between them. Moreover, the same R 's induces different meanings, $M(i)$, in other subjects **C** who intercept the representations. The objects that are used to communicate are shaped by meanings that are constructed in **A** and **B** iteratively and induce the constructions of meaning in **B** and **A** alternately. If communication is successful, then the internal meanings will come transiently into harmony, manifested by cooperative behavior such as dancing, walking in step, shaking hands, exchanging bread, etc. Symbols persist as books and stone tablets, while brains fluctuate and evolve until they die.

Observations of

electroencephalograms (EEGs)

Supposing that a mind can be defined as the functional collection of meanings in an individual, one biological approach to the problem of meaning is to study the evolution of brains, on the premise that animals have minds that are precursors of our own, and that their brains and behaviors tell us what essential properties are common to minds, theirs and our own.

Experimental measurements of brain activity (EEG) that follows sensory stimulation of animals show that sensory cortices engage in construction of activity patterns in response to stimuli [Freeman, 1975]. This operation does not correspond to that of filtering, storage, retrieval, or correlation. Each construction requires a first order state transition, in which a sensory cortex switches abruptly from one basin of attraction to another, thereby changing one spatial pattern instantly to another as in cinema frames. The transitions in the primary sensory cortices, visual, auditory, somatic and olfactory [Barrie, Freeman and Lenhart, 1996], are shaped by interactions with the limbic system, which establishes multimodal unity, selective attention, and the intentional nature of percepts [Freeman, 1999]. Interactions of the several sensory cortices with the limbic system occur in conjunction with goal-directed actions in time and space by reafference. Each cortical state transition is accompanied by synaptic changes throughout the forebrain that constitute learning, so that a unified and global trajectory is cumulatively formed by each brain over its lifetime. Each new spatial pattern appears to reflect the entire content of past and present experience [Skarda & Freeman 1987], which is the meaning in the brain at that moment.

The most important experimental finding is that the neuroactivity patterns in sensory cortex lack invariance with respect to repeated presentations of unchanging physicochemical stimuli that are fixed by an observer. Instead, the brain activity patterns are found to change slightly but significantly with any change in the values

of the stimuli, such as by changing the reinforcement, or adding new stimuli [Freeman, 1992]. Numerous tests of this kind support the conclusion that the activity patterns reflect the value and significance of stimuli for animals. The data preclude understanding brain activity as revealing a memory bank from which stored representations can be retrieved, as predicted many years ago by psychologists [Bartlett, 1932]. Each pattern formed in response to the presentation of a stimulus is freshly constructed by chaotic dynamics in the sensory cortex, in cooperation with the limbic system, which provides feedback control enacting the regulatory processes of attention and intention. The direct interactions among the sensory cortices and their indirect interactions through the limbic system express the history and existing state of the animal more than the actual incident stimulus. The pattern cannot be a representation of a stimulus or even of the meaning of a stimulus. It is a global active state that is induced by a stimulus, and that provides a next step in the evolution of the brain in the growth of experience [Piaget, 1930; Thelen and Smith, 1994; Freeman, 1999].

The neural basis for intentional action

Creating a representation is an intentional act, beginning with the construction of patterns of neural activity in the limbic system. That an intentional action is a product of the limbic system has been shown by use of lesions and by comparative neuroanatomy and behavior. [Herrick, 1948; Freeman, 1995]. In mammals all sensory input is delivered to the entorhinal cortex, which is the main source of input to the hippocampus and is the main target of hippocampal output (Figure 2). Goal-directed, intentional action must take place in time and space, and the requisite organ for time and space matrices is the hippocampus, which is often misconstrued and mislabeled as a 'short term memory' and a 'cognitive map'. These terms are metaphors, not operators.

Hunger is an example of an emergent

pattern of neuroactivity that expresses the brains' and bodies' requirements for metabolic fuel and building material. It does so by inducing a state transition in neural populations of the forebrain that are under the influence of sensory stimuli from the gut and from the brain's own chemical state chemoreceptors. Hunger's state transition is also shaped by neurohormones from nuclei in the brain stem. The consequent emergent pattern impacts the brain stem and spinal cord, leading to stereotypic searching movements that are adapted to the immediately surrounding world. Proprioceptive feedback from muscles and joints to the somatosensory cortex provides confirmation that the intended actions are taking place. The impact of the movements of the body on sensory input is conveyed to the visual, auditory and olfactory systems, where their sensory information is converted to perceptual constructs that incorporate the immediate multisensory stimuli along with reafferent messages (corollary discharges to sensory cortices of motor commands, which anticipate the impact on sensory input of the body movements of forthcoming intended actions), all in the context of prior learning. The perceptual constructs are transmitted to the limbic system, specifically to the entorhinal cortex, where they are combined to form Gestalts. When an animal detects an odor of food, it must hold it, move, take another sniff, and compare the two concentrations in order to decide which way to move next [Freeman, 1995, 1999]. The difference in strength has no meaning unless the animal has records of which way it had moved, when the samples were taken, and a basis for determining distance and direction in its environment. The same requirements hold for all distance receptors, so it is understandable that evolution has provided multimodal sensory convergence in order to perform space-time integration on the Gestalt, not on its components. These basic operations of intentional behavior are properties of the limbic system.

In the main description thus far, the flow of neural activity is counterclockwise (to the

left outside the brain in Figure 2) through proprioceptive and exteroceptive loops. Within the brain there is a clockwise flow of activity constituting reafference (the leftward arrows from "motor" to "sensory" systems). When a motor act is initiated by activity that descends into the brainstem and spinal cord, the entorhinal cortex sends the same or a similar activity pattern to all of the sensory systems, prepares them for the impact of the movements of the body and, most importantly, sensitizes them to the motor action by shaping their attractor landscapes to respond quite selectively to the stimuli that are appropriate for the goal toward which the action has been directed. These corollary discharges have been associated with the sense of effort [Helmholtz, 1879], reafferent signals (von Holst and Mittelstaedt, 1950), efference copies [Sperry, 1950], and prefference [Kay and Freeman, 1998]. They provide a significant part of the process of attention.

Linear versus circular causality in self-organizing systems

The conventional view of sensory cortical function holds that stimuli activate receptors that transmit to sensory cortex through a linear causal chain, with the eventual outcome being a motor response to the initiating stimulus. However, modeling intentional behavior with nonlinear dynamics shows that the stimulus is typically not the initiating event. Rather, it is the search for the stimulus that initiates an event, arising in the limbic system from recurrent prior search and its results. This is circular causality at the macroscopic level of intentional behavior [Merleau-Ponty, 1942]. Much lower in the hierarchy of brain organization is the neuronal interaction within primary sensory cortices, which provides for the destabilization of their mesoscopic states under the impact of microscopic sensory input [Freeman, 1999]. The role of reafferent limbic modulation is to facilitate the transition from a prior basin of attraction to a new one that is appropriate for the current intentional state. The state transition is triggered by the sensory input, which activates a previously learned nerve cell assembly that

is made of a small subset of cortical neurons. Access to the proper basin in which the cortex is placed is facilitated by the shaping of the attractor landscape of the cortex, which may be analogized to the expansion of the desired basin of attraction in the manner of Voronoi diagrams [Tipper, 1991]. This causal chain is also circular because the new state governed by a goal-dependent attractor is created by the neurons that are governed by the global process. This is how the stimulus-dependent neural activity of a few neurons can trigger a state transition, which then allows the entire domain of the primary sensory cortex to transit to an appropriate pattern, which, in the words of Hermann Haken (1983), "enslaves" the whole set of cortical neurons by its action as an "order parameter". This form of active state has been characterized by Ilya Prigogine (1980) as a "dissipative structure", in that it constitutes the "emergence of order out of chaos" through the expenditure of metabolic energy.

The similarity of the properties of neural activity in the limbic system to those in the primary sensory cortices [Freeman, 1999] indicates that populations of limbic system neurons also maintain global attractors that are accessed by nonlinear state transitions. This is the mechanism that is responsible for the genesis of both motor patterns that control goal-directed actions and the refference patterns that prepare the sensory cortices for the consequences of those actions.

A hypothesis about the relations of meanings and representations

The idea proposed here is that external representations are formed by the counterclockwise forward flow [left to right inside the brain in Figure 2] of neural activity that emerges at the microscopic level in motor neuron discharges and muscle contractions, which are coordinated at the mesoscopic level by interactions of neurons and neuronal populations. This global patterning places the motor systems of the brainstem and spinal cord into appropriate basins of attraction formed by

prior learning, while at the same time through refference effecting a change in the sensory inflow in accordance with goal-directed expectation. The construction of an external representation through an ordering of the control system of the musculoskeletal apparatus is a social action. It is aimed to project specific forms of matter and energy onto the sensory apparatus of other intentional beings, so as to elicit specific patterns of receptor discharge in their senses that are transmitted to their sensory cortices, thereby placing them into desired basins of attraction in landscapes formed by prior, shared learning.

The form that is given to the action-based external representation is determined by the meaning that has already been developed in the limbic system of the transmitting agent. This internal structure, which is often referred to (wrongfully, I believe) as an 'internal representation', is dependent on backflow [right to left inside the brain in Figure 2] of neural activity that serves as an order parameter, modulating and shaping neural activity patterns in the sensory cortices. A concomitant process of construction occurs in the receiving agent, but the resulting pattern of meaning is not the same as the meaning pattern in the transmitting agent, owing to the differences between individuals in their histories. Neither meaning pattern has the same form as that of the external representation. The fundamental difference in the nature of the internal and external patterns gives sufficient reason to avoid calling the meanings 'internal representations'.

It is noteworthy that sensory cortical populations transmit patterns of meaning continually, both before and after expected inputs have been transmitted and received, as well as whether or not expected stimuli have arrived. Therefore the meanings created through the constructions of unified sensory Gestalts encompass failures as well as successes in social communication, such as the absence of an expected sensory input, the misconstrual of meaning, or the outright creation of bogus patterns as in hallucinations and drug-induced fantasies.

I also infer that an organism that constructs and transmits representations cannot know their meanings until their sensory consequences have been delivered to its own limbic system. More generally, a poet, painter, or scientist cannot know the full meaning of his or her creation until after the act has been registered as an act of the self, nor until the listeners and viewers have responded with reciprocal representations of their own, each with meaning unique to the recipient.

Conclusion

Why do brains work this way? Animals and humans survive and flourish in an infinitely complex world despite having finite brains. Their mode of coping is to construct hypotheses in the form of neural activity patterns and to test them by movements into the environment. All that can be known is that which has been constructed, tested, and either accepted or rejected [Piaget, 1930; Merleau-Ponty, 1942; Freeman, 1999]. The same limitation of knowledge is currently encountered in the failure of machines to function in environments that are not circumscribed and reduced in complexity from the real world. Truly flexible and adaptive intelligence cannot operate in the real world without the construction of meaning. Since each meaning is defined as a place in the intentional structure of an individual, and since each individual is unique, the creation of shared meaning in a society of individuals is a complex and never-ending process of training in the construction of one's own representations, and education in the perception and interpretation of the representations of others. The ultimate test of the degree to which meanings are shared is the extent to which socially effective, conjoint actions can be sustained, based in the shared information disseminated by broadcast representations. That is the role of semiotics.

This global order parameter or operator by which meaning is constructed may be regarded as a mechanism supporting the

emergence of consciousness, which in the neurodynamic view is a global internal state variable comprised of a sequence of momentary states of awareness [Freeman, 1995; Hardcastle 1995]. Its regulatory role can be compared to that of the operation of a thermostat, which determines the difference between the sensed temperature and a set point, and initiates corrective action by turning a heater on or off. The machine state variable has a very brief history and no capacity to learn or determine its own set point, but in principle is the same: the internal state is a form of energy, an operator, a predictor of future states and actions, and a carrier of meaning that is available to the system as a whole. The operation of such a simple feedback device is prototypic, an evolutionary precursor, not to be confused with animal states of awareness, any more than tropism in plants and bacteria is to be confused with intentionality. However, there is no reason in principle to preclude the development of hardware systems that embody the dynamics by which animals and humans construct meaning. Certainly such devices will require prolonged education through their equivalent childhood and adolescence.

Another necessary condition for success will be to endow such systems with the capacity to make and deploy representations, so that observers can determine whether the operations and patterned contents of the internal global state variables in the devices have achieved the construction of meaning. Such semiotic exchanges between observers and their devices would constitute the experience of social communication, much like that between humans and simpler animals. Whether the devices could be considered to be conscious would be a sociolegal matter for courts of law to decide, not a problem for scientific analysis or proof [Freeman, 1995].

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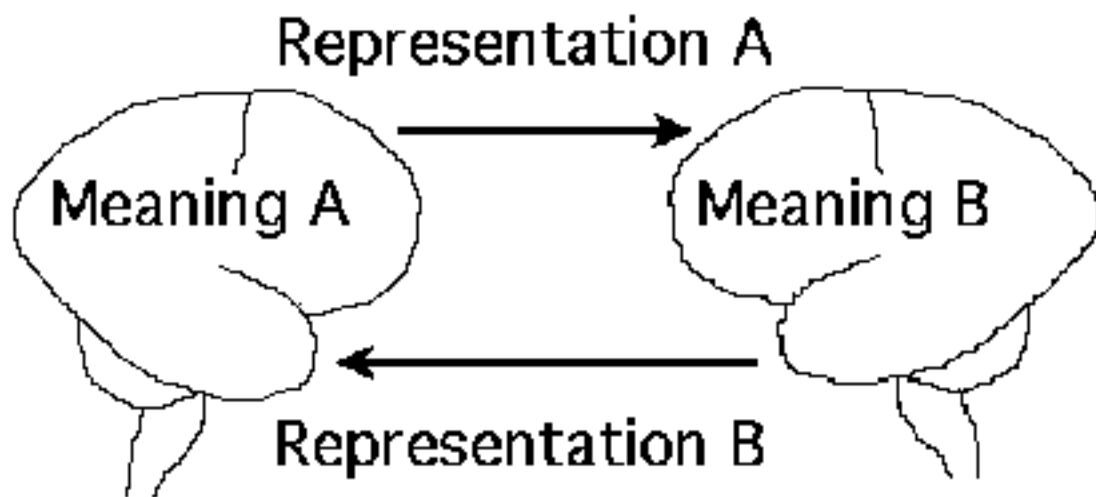


Figure 1

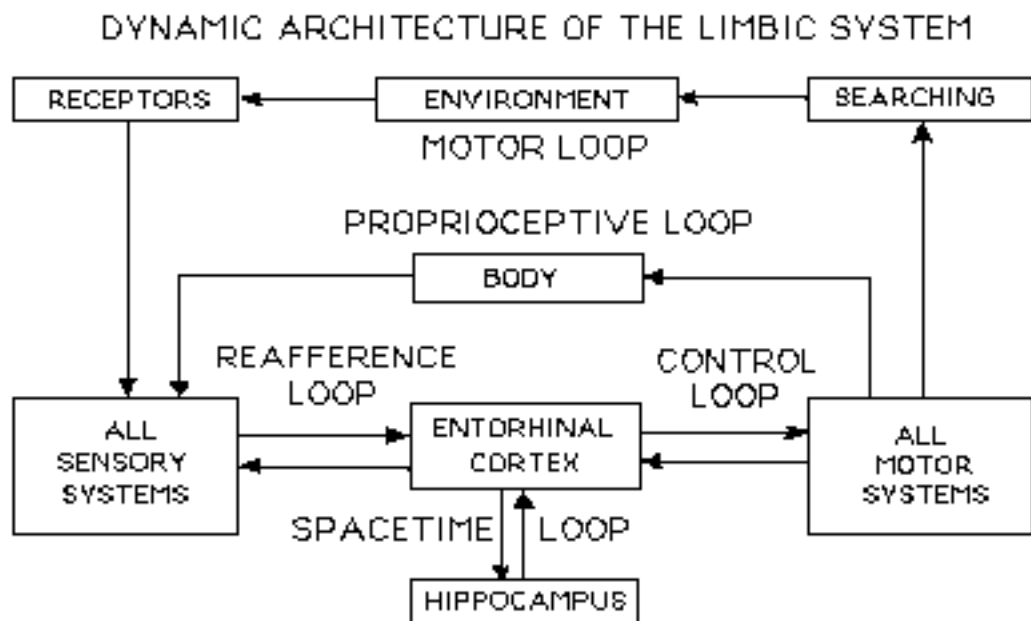


Figure 2

