Nonlinear Brain Dynamics and Intentionality

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Abstract

The core problem of intentionality is posed by the rapid transition [Heidegger: transposition, transcendence] between specific object and abstract concept — between the specific and the generic in both material and conceptual aspects, not between neural and psychic aspects. A solution is proposed in neurodynamics by analyzing fields of neural activity that self-organize in the brain. The neural activity is hierarchically organized. Sensory inflows from receptors and motor outflows to muscles are by pulses on axons at the microscopic level, the level of the phantasms of Thomas Aquinas and the inaccessible raw sense data of phenomenologists. Below is the flux of molecules at submicroscopic and quantum levels. Above is the self-organization of local fields into spatial patterns of pulse and wave activity in patterns at the mesoscopic level, the first and incomplete stage of perception where abstraction and generalization take place. Next is the organization of widespread fields of coordinated neural activity at the macroscopic level. The fields are large enough to include many areas of the brain. At this level the perceptual contents in patterned activity include the locations in time and space of objects and events. These patterns are not representations of stimuli, actions, thoughts, beliefs, etc.; they are expressions of knowledge in active support of perception, comprehension, prediction, and selection of appropriate courses of inaction or action. They do not result from computations in any literal mathematical sense. They are dynamic entities akin to whirlpools and eddies in rushing streams, unlike numbers in computers. These self-organized goal states through recursive self-similarity include macroscopic perceptions of present states, projections of future states, plans at the mesoscopic level for action to achieve them, and trajectories of microscopic pulses that direct muscular activity in goal-directed actions modulated by sensory feedback. This hierarchy gives the behaviorist reflex arc, the pragmatist action-perception cycle, and the phenomenologist intentional arc. The proposed explanation in terms of field neurodynamics is consistent with the nonrepresentational systems of Aquinas, Heidegger and Merleau-Ponty that avoid the Cartesian subject-object split. Neurodynamics can explain first intention — understanding of perception as direct grasp of objects and events by animals and prelingual children — but it lacks at present the

experimental data on brain activity that will be needed to explain second intention, by which the self comprehends the immanent action of understanding itself.

1. Introduction

Everyone knows the experience of smelling the scent of a rose or any other of a myriad of odorant substances that we perceive as odors. How does this happen? How do we interact with a material object and then know what it is and what it means for us? A philosopher would say that we intend the rose; a cognitivist would say that we form a representation; a material scientist would say that we extract information from the chemicals and process it into a form suitable for comparison with information stored in memory. These are complicated words and concepts that we use to describe an elementary process. We need to simplify. We know that we share the process with animals, which quite often have better acuity than we do, though not our depth of comprehension, so we can study the process in the brains of animals that are less complex than ourselves. This elementary process occurs in all our senses, not just the traditional five of sight, sound, touch, hearing and smell, also gravity, muscle tension, muscle length, joint angle, and countless senses for chemicals concentrations, pressures, local temperatures, and volumes throughout our bodies and brains. The sense of smell is by far the most versatile and universal, rivaled only by the immune system, yet olfaction is also the simplest and most ancient.

For these reasons olfaction in rabbits is the paradigm of choice for study to understand the elementary process and to compare the biological and philosophical descriptions of brain/mind function to find commonalities. We can find answers to the question: How can we so simply and elegantly cross the border between odorant and odor, between the material and the perceptual, to perceive the smell of a substance or to create a chemical with a desired fragrance [Burr, 2002]?

2. The neurobiological paradigm

Experimental neurobiologists are privileged in the search for understanding the process, because we have been granted the opportunity to record and measure the activity of neurons in the nose and in the many parts throughout the brain where the ongoing neural activity is modified by the simple act that intends a rose, or represents it, or processes its information into knowledge. Our group has recorded electrical activity from electrodes we fixed in the brains of rabbits trained to respond by sniffing or chewing after they learned the significance of simple odorant chemicals. By their actions we proved that they could identify the specific odorants that we presented to them. The rabbits acted the way they did because each time we presented an odorant we accompanied it by a reward or punishment that made the odorant meaningful for them. Without this reinforcement the odorants were meaningless for the rabbits, and they learned to ignore them. With reinforcement they learned actions by which to get rewards and avoid punishments. They also learned to predict that any of several odorants would come in the near future, and they prepared their bodies to detect them and take appropriate action in response to whatever might occur, including the unexpected or unknown events, which in their uncertain world could occur at any moment.

All these properties we derive from classical behaviorism, by which psychologists describe and control such behaviors in terms of schedules of reinforcement, and neurobiologists describe them in terms of hierarchies of reflexes. Neurobiologists observe the neural activity by recording the electric potential differences in and around the brains of the animals as they anticipate, detect, and respond appropriately to the odorants in their learned repertoires. There is a notable reciprocity between the intention of a rabbit to perceive a signal of import and the intention of a researcher to perceive the neural activity. The animal prepares its body by orienting its sensory receptors in the nose and sniffing; the researcher prepares and places electrode arrays, rigs electronics to amplify, filter and measure them, and creates displays to bring the measurements to the observer's senses. The designs of the arrays, the filters, and the methods for measurements to extract information all depend on the expectations of the researcher. The details are complex and of interest only to specialists, but in principle the process is the same. From our respective experiences we and our rabbit predict what the future holds; we plan appropriate tests of our predictions; we make the tests and detect the changes in our sensory input that are caused by our actions in making the test; we classify the results of our test by whether or not what happens conforms with what we expect to happen; and we modify our expectations accordingly.

Of course, the rabbit is much simpler, and therein lies its utility. From its training it expects to receive any one of two or three odorants at some time in the near future, and it samples the air each time it breathes in. When an odorant comes, the rabbit detects it with its nose, determines with its brain which expected event has occurred, and with its body takes appropriate action such as sniffing or chewing or relaxing. The crux of the problem lies in the neural event by which the determination occurs in the brain of the odor from the odorant. We divide the neurobiological process into stages. In the first stage we observe the effect of the odorant on the receptor cells in the nose. In the second stage we observe the effect of the activated receptors on the olfactory brain. In the third stage we observe the effect of the olfactory system on the whole brain. Lastly we observe the effect of the brain on the body, as the rabbit responds to the odorant. The crossing from odorant to odor occurs in the second and third stages. We observe the process in these stages with electrodes in the brain by which to record, measure, and model the neural activity.

3. The first stage: Information processing and linear causality

Each electrode inserted into the nose or the brain yields two forms of electrical activity. We see one form in trains of electric pulses (spikes, action potentials, units) from individual neurons. We see the other form in continuous waves of electric current (dendritic potentials, local field potentials, electroencephalograms, EEG) from populations of neurons. The study of pulses is based on the view of the olfactory receptors or brain areas as networks of individual neurons. The study of waves is based on the view of the same neurons generating continuous space-time fields, in which the identities of the neurons are submerged in the populations. The differences in views resemble those between the psychological analysis of individuals in families compared with sociological analysis of the organization of cities and states. At the start of the neurobiological experiments the electrodes are shaped and placed to maximize the detection of either pulses or waves, and the recordings of electrical activity containing both forms are filtered to separate the pulses and the waves for analysis. The data from each stream are used to construct hypotheses about the functions of the olfactory brain, on the one hand as discrete networks of neurons that are connected by junctions, the synapses, and on the other hand as tissues that contain such high density of neurons and synapses that the tissue can be described as a continuum, analogous to ways in which molecules can be described as forming a liquid or gas.

A selective synthesis of both views is essential for understanding brain function. This is because brains work at many levels of organization. An act of perception involves all levels of activity, ranging from the attachment of individual molecules of an odorant to the molecular structures on the surfaces of olfactory receptor cells to the initiation by the rabbit of sequences of social behaviors intended to enhance the likelihood of the species to survive. The guiding principles of experimental neurobiology are that we record activities of both kinds as the neural correlates of the process by which an odorant is comprehended as an odor, and that we use our observations of the correlates to construct explanations in the form of dynamic models of the brain systems that perform the process. Notably these numerical correlates unite patterns of neural activity with patterns of goal-directed behavior, not with consciousness or verbal descriptions of phenomenological states. We have no measure of what rabbits feel or what they are conscious of. We deal here with the process of inductive category formation in the accumulation and intentional utilization of knowledge, for which emotion is an integral part [Freeman, 2001], and not with the 'hard problem' at the core of consciousness studies [Chalmers, 1996].

The network model is assumed to begin with the reflex arc [but see Section 6], in which the stimulus has the form of molecules of odorant that bind to receptor cells at the molecular and quantum levels. The binding releases a wave of electric current that initiates and sustains firing of pulse trains from just those receptor neurons that can selectively bind the molecules. According to various authors [Burr, 2002] the microscopic neurons encode sensory information in their pulses and transmit it by axons into the olfactory brain, where it is directed by switching networks to selected neurons that act as feature detectors. The selected neurons send the processed information to associational areas of the brain. The steps beyond are conjectural: higher areas are thought to compare the input information with previously stored information retrieved from memory. The best matching pattern is thought to be selected and sent to the motor cortex, where an appropriate response is selected for transmission into the motor systems of the brain stem and spinal cord. All this must occur in time frames lasting on the order of half a second.

4. The later stages: The action-perception cycle

The field theoretic model begins with the action-perception cycle, not with the stimulus, but instead with the formation in the forebrain of a macroscopic pattern that embodies anticipation of a desired future state of the brain and body, such as finding food or avoiding danger. Constructed within this macroscopic pattern are mesoscopic activity patterns that govern local sensory and motor populations that control the actions intended to achieve the goal. Within each population the microscopic neurons are directed ("ordered") to fire pulses in prescribed sequences. These individual neurons also receive immediate feedback from sensory receptors in the muscles and joints that are needed to continuously adapt the intended movements of the body to the intended goal. Little is known about the neurobiology of these two downward steps. They are modeled in engineering terms by predictive systems such as those for controlling the flight of an airplane, which have an over-arching level in which the goal is selected by choosing a flight plan, outer loops that set the control surfaces to direct the aircraft to its goal, and inner loops that regulate the control surfaces in the wings and tail to compensate for wind turbulence. So also the macroscopic pattern establishes a context within which the local mesoscopic patterns are conceived to organize in multiple areas, which establish the local context in which neural networks perform the required tasks.

The movements of the body in every intended overt action modify the positions with respect to the environment of the receptor cells in all sensory systems. The modifications change the sensory input. These self-induced changes are anticipated and predicted from past experience. The predictions are communicated from the motor modules to the sensory modules of the brain by copies of the motor outflow known as corollary discharges in the process of preafference [Kay and Freeman, 1998], which is the basis for focused attention. The corollary discharges prime the sensory areas by making them selectively sensitive to each of the expected stimuli in the search for odorants signifying food or danger, be they from carrot or fox, cabbage or man.

Studies of neural fields [Freeman, 2004a,b, 2005a, 2006] show that the impact of the pulses from the receptors on the olfactory brain is not at all like receiving a message that needs to be answered. The millions of pulses with each inhalation cause a major change in function, which is equivalent to the change in state from a gas to a liquid [Freeman and Vitiello, 2006]. The nearly random activity before the impact is increased in amplitude, and at some point it condenses much as would water molecules forming a raindrop. In physical terms the impact induces a phase transition in the olfactory brain, which forces it out of its rest state into a search for a new state into which to converge. This is a brief state of search through the selective classes of sensitivities stored by modifications of synaptic strengths from prior learning. We conceive each cortical dynamical system as having a state space through which the system travels as a point moving along a path (trajectory) through the state space. A simple analogy is a spaceship flying over a landscape with valleys resembling the craters on the moon. An expected stimulus contained in the omnipresent background input selects a crater into which the ship descends. We call the lowest area in each crater an ‘attractor’ to which the system trajectory goes, and the set of craters as basins of attraction in an attractor landscape. There is a different attractor for each class of stimulus that preafference has primed the system to expect, each surrounded by its basin. The landscape is surrounded by a catch basin that signals unknown stimuli [Skarda and Freeman, 1987] that might be important. These signals lead to a behavioral action known as the ‘orienting response’. The animal receiving an unexpected stimulus freezes and directs its senses in search of something unknown and threatening. If the unknown stimulus is accompanied by reinforcement, then a new attractor forms, which changes all of the others by deforming the landscape. If there is no reinforcement, the system automatically adapts by habituation to block cortical reception in the future. These processes of association and habituation are the essence of an associative memory. There is an exclusion principle at work in that only one attractor can be selected at a time, though possibly rapid rotation among two or more attractors may occur.

The dynamics in each sensory cortex (not just for olfaction but also vision, hearing and touch) converges within two or three tenths of a second to an attractor, which transmits its message by a modality-specific wave packet [Freeman, 2000]. The content of the message is determined by the previously learned synaptic connections in the sensory cortex, which constitute the integrated record of knowledge laid down during prior experience with the stimulus. That synaptic network determines an attractor and its basin in the landscape sustained by each cortex. The newest arrival of the stimulus-evoked action potentials selects a basin, which initiates the process of generalization to the class of the detected stimulus. With each arrival the process of learning continues to refine and update the local synaptic network. As the system converges to the attractor in the basin, it deletes the extraneous information about which particular receptors receive the stimulus, which constitutes the process of abstraction. The attractor determines the transmitted message, not the stimulus, which merely selects and modifies the transmitted signal. Owing to the large surface area of cortex that is integrated by the attractor and the divergent-convergent topology of the transmitting axons, the messages are broadcast through the brain. The most salient among its targets is the limbic system. This is the core structure of every vertebrate brain that is identified with the expression of emotion. Its key structure, the hippocampus, was the first cortex to appear in the phylogenetic evolution of the brain [Maclean, 1969], and it well deserves its appellation, archicortex ("ancient cortex"). The hippocampus sustains the neural machinery by which sensory events and objects are assigned spatial locations in the environment and times of occurrence in the stream of life history. Time and place are indelibly linked to each other and to stimuli in the hippocampus. In mammalian brains the wave packets of all sensory cortices converge either directly in olfaction or by relays to the hippocampal vestibule, the entorhinal cortex. There they are integrated into a multisensory pattern as they pass through the hippocampus back to the entorhinal cortex. Every event must make this passage, if it is to be assigned a space-time location in the stream of personal experience. These properties are commonly referred to as the spatial "cognitive map" and the temporal "short term memory" provided by the hippocampus [O'Keefe and Nadel, 1978; Buzsaki, 2002].

The early wave packets are modality-specific for each sensory area. While they are predominantly determined by the pre-existing pattern of the expected input that is embedded in the local synaptic modifications with past learning and fielded by preafference, they are slightly modified by learning with every successive input. The collective modification is the basis for self-assimilation by which the animal continuously up-dates its relation to the environment. The combined spatiotemporal pattern that is assembled in the hippocampus is re-transmitted by stages to all sensory areas. The result is that within half a second of the original event there emerges in the brain a global pattern of cortical activity that is participated in by every sensory area [Freeman and Burke, 2003: Freeman and Rogers, 2003], that implements the process of preafference, and that issues as a fresh motor command. This construction of a macroscopic pattern completes the action-perception cycle with assimilation [Freeman, 1995], literally within the time frame required for the blink of an eye.

5. Circular causality

One may ask where in the brain does the macroscopic pattern exist and at what level of organization? The answer is that all levels of organization of all parts of brain and body are simultaneously engaged with the material, formal and social environments. To focus again on olfaction, the molecular structures of the receptor cells in the nose are active in binding odorant molecules from the air stream. So also are the myriad synapses in the sensory and motor areas of cortex and at the neuromuscular synapses on muscle cells, which bind neurotransmitter molecules at the submicroscopic level. The networks of neurons in the olfactory brain are active in preprocessing the information delivered by pulses from receptor cells into cortical networks, executing the essentially engineering operations of amplification, range compression, normalization, filtering, and selective enhancement of the information [Freeman, 1999]. The entire olfactory brain is galvanized in a phase transition by which the stimulus selects the class to which it belongs, and the entire system transmits a wave packet throughout the basal forebrain including the limbic system. The subsequent formation of a macroscopic pattern integrates the activity of the entire forebrain including the limbic and motor systems. The pattern provides the context in which the appropriate behavior self-organizes, containing the trajectories of neural activity and limb movements that are required to achieve emergent goal states. Molecular, cellular, and mesoscopic assemblies are modulated and directed at all times, everywhere, and at all levels. How might this orchestration take place?

One might ask a similar question about any large-scale, self-organized physical process such as a hurricane or a tree. How does each molecule of air or water conform its trajectory into the gigantic vortex that feeds on solar energy? How does each pore on every leaf in the sunlight coordinate with every hair on every root branch in the ground? Correspondingly, how does each molecule of neurotransmitter substance and each neuron and each local assembly conform to the global organization that we observe in animal and human behavior? These questions we can answer now by combining neurobiological observation and experimentation with theory from physics, chemistry and mathematics [Prigogine, 1980; Haken, 1983]. But hurricanes and trees cannot intend whereas brains can and do intend. The difference is two-fold: hurricanes and trees cannot remember and learn from their past, and neither trees nor hurricanes can direct the movement of their bodies through their environments. They have no brains. Only animals with brains have the machinery for anticipating future states, planning for deployment of their bodies in pursuit of satisfaction of perceived needs, predicting the consequences on sensory inflow of their own actions, and above all for self-assimilating by which they bring their brains and bodies into conformance with their environments. In short, they lack the mechanisms required for intentionality.

It is immediately apparent that intention spans the entire range of material, psychological and social behaviors, from the most distant conception of survival and procreation to the molecular changes in nerve cells that enable sensation, learning, and muscle contraction. The material basis at each level and its teleological relations to levels immediately below and above are well described by the particular science that is directed to the level. Of particular concern is the relation between levels that is described with the concept of circular causality [Haken, 1980]: in self-organization the higher-level order forms by the interactions of lower-order parts. His now classic example in physics and engineering comes from the dynamics of a laser. The parts are the atoms in a gas that oscillate at frequencies in a distribution about some mean value, when they are in a state of low energy. When energy is pumped into the atoms, they oscillate more strongly and interact with each other more strongly. At some high threshold they undergo a state transition and oscillate all at the same frequency. The high-energy oscillation is called an “order parameter”, because the atoms that generate the oscillation are “ordered” (“enslaved”) by the whole to oscillate at one frequency. The reason this process is described as “circular causality” is that the particles (like neurons) create the field (like the wave packet) and the field imposes order onto the particles. Similarly in the olfactory brain at low energy before a stimulus input arrives, the neurons emit pulses seemingly at random with a distribution of pulse frequencies. When their energy level is increased by excitation from olfactory receptors, their pulse frequencies increase. At some threshold the whole population interacts so strongly that all the neuron potentials oscillate at the same instantaneous frequency, though with different amplitudes. The population signal seen in the amplitude pattern of the wave packet at that frequency is an order parameter that brings all of the neurons into some degree of synchronous oscillation [Freeman and Vitiello, 2006].

The analogy is limited, because atoms are all indistinguishable, whereas neurons all differ from one another, no two being identical. Whereas all the atoms are locked into the one order parameter, the neurons in a population have varying degrees of sharing in the common signal. Owing to their individual differences the classical descriptions from statistical mechanics are not adequate to describe population neurodynamics. Descriptions using concepts from classical thermodynamics certainly apply in terms of the requirements for disposal by brains of waste heat and entropy, as well as essential constraints on brain temperature, pressure, mass and volume that are self-regulated. The analogy does have great value, because it expresses a fundamental property of brains in a simple way: populations of neurons interact by excitation and inhibition through synaptic transmission and create order parameters that regulate the same neurons. This is circular causality. We observe the individual neural activity in pulse trains on axons; we observe the order parameter in waves of dendritic currents. The relation between pulses and waves is bidirectional. We predict the wave densities from pulse densities by averaging over the parts that form the whole. We deduce the effects of the waves on the pulse densities by calculating differences in wave densities. Integration carries us to the higher level; differentiation carries us to the lower level. These processes of summation and differencing occur simultaneously in all areas of cortex. The predominant direction of information flow through these processes in sensory areas is upward from individual neural activity to population densities; the predominant direction in motor areas is downward from population wave densities to more individually structured trajectories of pulse densities.

6. The unity of circular causality across all levels

Looking downwardly, neurons are microscopic parts of mesoscopic populations, yet each neuron is a semi-autonomous whole that develops and maintains complex relations among its parts. It devotes most of its lifespan to janitorial functions; the typical cortical neuron fires a pulse lasting 1 ms at an average rate of 1/s, which would scale to one full day every three years. Yet it is ceaselessly active at all times in responding to input from on average ten thousand other neurons, by which it is modulated through the order parameter. Each of its parts is a whole that is organized by assemblies of macromolecules that provide the energy for generating electric fields, opening and closing ion channels, and maintaining chemical balances. Each macromolecule is an organized assembly of atoms that performs a designated task that depends on collective, patterned action expressing an order parameter. Looking upwardly, mesoscopic neural populations are components of on-going macroscopic fields comprising organized actions of the whole brain. The brain is one organ among many in the body that cooperate continually in directed actions. The body is embedded in organic relations with the material and social worlds, and so on. Each of these levels generates order parameters at differing scales of time and space, and operates with entities, states, and state variables that are unique to the point of view taken by scientists engaged in systematic study at each level. Yet brain wave dynamics is scale-free [Barabásí, 2002], owing to the finding that its wave patterns of electrical activity are self-similar at all scales of time and space, as shown by measurements of distributions of its dynamic properties, most obviously those of the cortex [Freeman, 2005b, 2006]. It is the scale-free dynamics that enables the brain to participate in and organize all levels of function simultaneously by transactions that extend seamlessly across the entire range, yet which can be abstracted for measurement and analysis at each desired level with its pertinent scales of measurement.

The reflex arc actually begins not with a stimulus but with the intention of the investigator, who selects and delivers a stimulus to the subject. The stimulus is a pattern of chemical energy that impacts on individual receptors at the atomic level with binding of molecules of scent to the surfaces of receptor cells, initiating cascades of biochemical reactions resulting in microscopic pulses transmitted to the brain. The impact of myriads of pulses with inhalation destabilizes the olfactory brain and changes the order parameter to an intracortical search mode. Convergence to an attractor means that the collective populations enter into an ordered state that modulates the pulse trains of the entire olfactory brain, sending a signal that is carried by the patterns of myriad microscopic pulses to other parts of the brain. The pattern of the wave packet, being mesoscopic, is not detectable by observing the pulse trains of any small number of neurons; it is only seen in large averages. The convergence of multiple wave packets supports the emergence of a global brain state that provides an order parameter that includes the motor areas simultaneously with the sensory areas. This macroscopic context modulates the mesoscopic populations that organize the motor areas into controlled sequences of oscillations and shape the sensitivities of the sensory areas by selection of attractor landscapes in preafference. The arc is completed by regulation of microscopic pulse trains on motor neurons, which release the neurochemical synaptic transmitter molecules that are required for muscle contraction.

Whatever the intent of the investigator, the intentional arc begins with the intention of the animal as expressed in its macroscopic goal state, extends to the microscopic level of muscle contraction, resulting in changes in the microscopic binding of chemicals to chemoreceptors, photons to visual receptors, and so on, with closure of the arc by assimilation and up-dating of the macroscopic state.

7. From sensation to perception to conception; from goal to plan to action

The above descriptions of the neural correlates of intentional action and perception, when viewed in terms of scale-free brain dynamics across the broad range of scientific disciplines, leads to the view that engagement of the individual with the environment is simultaneous at all levels. The material engagement takes place in the immersion of body and receptors in gases, liquids and solids governed at the atomic level by quantum field theory, and at macroscopic levels by Newtonian physics through forces that modulate the firings of stretch receptors in muscles, pressure receptors in skin, joints internal organs, and vestibular receptors for gravity and acceleration of the head. These chemical and physical forces permeate brains and bodies with continuous presentation of bodily information to the brain and compensatory actions being initiated by the brain. At the mesoscopic level there is preconscious apprehension of the influx of new relationships between body and environment that go far beyond information processing in presenting confirmations or disclaimers of anticipations regarding the continuity of the fabric of the world and the place claimed by the individual. These surmises about the impending future accompany the preparations for rest or for incipient action to deal with predicted or unexpected contingencies in the surround, the arena of perception. Yet this is not all. Embedding the perceptual and premotor activities of body and brain is the guiding matrix of goals, ranging in scope and complexity from what to do in the next few seconds in the face of opportunity or danger to lifelong ambition to flourish and prevail. It is this self-structured dynamic edifice of anticipations rooted in the accumulated self-assimilations of a lifetime of knowledge that modulates, enriches, and integrates the experience so actively reflected in mesoscopic and macroscopic patterns of brain activity. We have also discovered their traces in electrical fields at the surface of the brain and scalp, but we cannot yet read them, because we don’t yet know how.

This description of intentional brain dynamics was presaged seven centuries ago by Thomas Aquinas [1272], who dismissed the passivity of the Platonic soul by conceiving intention as taking action (*intendere*) and coming to know the world by self-assimilation (*adequatio*), which is conforming the body and brain with the environment, unlike the Aristotelian processing and storing of forms (information). In the case of the intentional arc the goal pre-exists the action, while in the case of the reflex arc the goal exists only after completion of the action Aquinas wrote [Q 85, A 2] that there are two kinds of intentional of action. One is transitive action by mechanistically thrusting the body into the world in the manner of a robot or other machine. The other is immanent action by understanding, which distinguishes the actions of animals and humans from those of machines that act without comprehending what they are doing. Understanding includes contemplative withholding of action but still with reference to or engagement in the world that provides knowledge through self-assimilation through learning from the senses, herein differing from idealist conceptions that understanding is derived solely through reference to innate structures in the brain. Understanding does not occur at the microscopic level of single neural activity of pulses, which is unique and ephemeral and directly related to the particular stimulus that drives it. This is the level of the "phantasms" of Aquinas, which are likenesses of a thing and not the thing, in the manner that trains of action potentials bear information presenting the likeness of a stimulus to the brain but not the stimulus. In the manner of all unique events, the phantasms (the patterns of the pulses, the raw sense data) are unknowable.

The mesoscopic level is that of the intelligible species, which forms by abstraction and generalization over multiple sequential phantasms. Here is the first step of crossing from the realm of the material to the realm of the perceptual. The transition begins in sensory areas with modality-specific wave packets, which embody a selection of all stored experience that is immediately relevant to the intended inputs. The wave packets are not fully intelligible, because they lack multi-sensory integration and orientation in time and space from convergence and passage through the limbic system. Aquinas wrote [Q 79, A 4]: "Therefore we must say that in the soul is some power derived from a higher intellect, whereby it is able to light up the phantasmata. And we know this by experience, since we perceive that we abstract universal forms from their particular conditions, which is to make them actually intelligible." His "light up" appears to correspond to the stage of self-assimilation when a macroscopic state emerges following the limbic integration of mesoscopic wave packets and preafference [Freeman and Burke, 2003; Freeman and Rogers, 2003]. That macroscopic order parameter modulates all sensory cortices and includes the motor areas, which must be engaged in the process of deciding what to do in the light of new integrated input from the senses. The new state of knowledge is an engagement with the situation of brain and body in the world that by self-similarity contains mesoscopic preparatory states in both sensory and motor areas for planning action and predicting its sensory consequences. In the manner of scale-free systems the dynamic engagement occurs at all levels simultaneously, be they material, formal, or social. Through mesoscopic and macroscopic constructions the brain conceives, grasps, and approaches by sequential actions with the body what Merleau-Ponty called "maximum grip" immediately and directly in the way that an aircraft pilot, a car driver, and a tennis player experience the instruments as extensions of the body, not as inner manipulation of symbols and representations or exercise of computational logic. This elemental process does not posit consciousness; there is no need for that hypothesis. Self-awareness in these actions is by neural mechanisms not yet adequately examined in humans to provide the experimental field data required to build the appropriate theory, but it is clear that the recursive embedding provided by circular causality in macroscopic patterns of transient global synchrony will be identified as crucial in the process.

8. First intention and second intention

This description of the neurodynamics of intentionality has been made possible only in the past few years, equally by advances in technology that enabled simultaneous EEG recording from large electrode arrays implanted onto the surface of the brain or on the scalp of humans, and by advances in theory that enabled modeling the EEG patterns using concepts from nonlinear dynamical theory [Freeman and Vitiello, 2006], neuropercolation theory [Kozma et al., 2005], and scale-free dynamics [Barabásí, 2002; Freeman, 2006]. These developments open the way to reconsider long-standing differences between cognitivists and phenomenologists in their interpretations of intentionality. Descartes abandoned this concept in his dualist, subject-object description of the soul operating the brain like a pilot controlling machine functions using representational logic and mathematics. Intention was re-introduced by Brentano [1889/1969] as the basis for distinguishing the representations and operations on them of humans who know what they are doing from those of machines that do not know. The usages by his successors have led to Searle's [1983] definition of intentionality as "aboutness", because a thought or a perception is "about" something. This interpretation suffers the intractable difficulty of grounding symbols in machines to the entities they represent. For example, what is the relation between a word in a computer memory and the real person it represents? Similarly, how does the firing of neurons in the cortex of the fusiform gyrus signify the perception of a face, and how does that firing "cause" one to experience the person whose face it is?

Heidegger [1975/1988] reintroduced what he called "the enigmatic phenomenon of intentionality" in forms close to those of Aquinas, addressing what he called "the central problem of philosophy", the same as that with which this essay began: in his terms, "… the 'transposition' [transcendence] of the Dasein over to things". … "But what is originally transcendent is not things as over against the Dasein: rather, it is the Dasein itself which is transcendent in the strict sense. Transcendence is a fundamental determination of ontological structure of the Dasein. … It will turn out that intentionality is founded in the Dasein's transcendence and is possible solely for this reason — that transcendence cannot conversely be explained in terms of intentionality. [p. 162]". He conceived the Dasein as neither objective nor subjective, and in those terms dealt with two "misinterpretations". First was the "common sense" assignment of intentionality to the subject (Searle [1983] would say the firing of neurons) causing perception of an object, thus maintaining the Cartesian subject-object separation of representationalism. Heidegger wrote that this view characterized "… intentionality as an extant relation between two things extant, a psychological subject and a physical object. The nature as well as the mode of being of intentionality is completely missed. … The intentional relation to the object does not first fall to the subject with and by means of the extantness of the object; rather, the subject is structured intentionally within itself. … [I]ntentionality is not an objective, extant relation between two things extant but the comportmental character of comporting, a determination of the subject [pp. 60-61]." The second misconception was that "the usual conception of intentionality misunderstands that toward which — in the case of perception – the perceiving directs itself. Accordingly it also misconstrues the structure of the self-directedness-toward, the intentio. This misinterpretation lies in an *erroneous subjectivization* of intentionality. … Intentionality is neither objective nor subjective in the usual sense, although it is certainly both, but in a much more original sense, since intentionality, as belonging to the Dasein's existence, makes it possible that this being, the Dasein, comports existingly toward the extant." [pp. 63-65]. This misconception is common among psychologists who conceive intention as a mental state of goal-directedness.

Here again is the core problem: understanding the relation between the abstractions and generalizations in the self and the material objects and events that are understood, and how they are understood through likenesses, the phantasms of Aquinas and the action potentials of neurobiologists. The dynamical view proposes that a self-similar hierarchy of patterns, emerging from the structures of knowledge that are stored in the synaptic tissues of the brain, is continually modified by interactions with the multiple environments of the body and brain. In some deep sense this patterned activity expresses the being that Heidegger conceived as the Dasein, but at present with a significant limitation that constrains intentional neurodynamics to describing only first intention that animals share with children still too young to remember their lives or to distinguish themselves from others. Operationally the capability is defined by the mirror test: toddlers in front of a mirror look behind it to see who is there; a few months later they watch themselves touching themselves. At present the evidence for macroscopic neurodynamics comes only from animals that cannot pass the test. Second intention in which the self reflects on the process of comprehending the likenesses provided by first intention is barely touched by neurobiologists, despite major efforts to explore consciousness and awareness. This is the domain of phenomenology. Hubert Dreyfus [2006] has described remarkably close correspondences between brain dynamics and the basic conceptions of the structure of intentional behaviors as conceived by Heidegger and Merleau-Ponty, subject only to the limitation that phenomenology can only begin with consciousness having concepts that emerge far above the raw sense data and wave packets. Owing to entry at this high level it is apparent that phenomenologists cannot reach down to the level of sensation so as to distinguish between sensation and perception, as neurophysiologists distinguish them, which is shown by this exchange between Merleau-Ponty [1966] and a conference organizer:

> *M. Parodi.* Could you tell us what is your most important contribution on this question of fact. You began with very clear examples: we think we perceive things which we really only see in part, or more or less. What, according to you, is the essential element in this operation?
> *M. Merleau-Ponty*. To perceive is to render oneself present to something through the body. All the while the thing keeps its place within the horizon of the world, and the structurization consists in putting each detail in the perceptual horizons which belong to it. But such formulas are just so many enigmas unless we relate them to the concrete developments which they summarize.
> *M. Parodi.* I would be tempted to say that the body is much more essential for sensation than it is for perception.
> *M. Merleau-Ponty*. Can they be distinguished? … [p. 42]"

Clearly M. Parodi did not grasp Merleau-Ponty's position, which is that sensation does not exist as a prior process for phenomenologists.

The dominant contemporary approaches used by researchers to understand both human and machine intelligence rely on computational and representational models. One reason is the clarity and simplicity of logical positivist concepts describing brain activity in terms of information, compared with the relative obscurity and impenetrability of the verbal descriptions by phenomenologists of their ideas. For non-scientists the arcane descriptions by brain dynamicists may appear just as opaque as Heidegger's and Merleau-Ponty's prose in translation appears to them, but scientists have the advantage of experimental grounding in brain physiology, the interpretation of which may be facilitated by translating concepts between fields. Alternative approaches to incorporate intentionality include those of pragmatists such as John Dewey [1914]: "Actions are not reactions to stimuli; they are actions into the stimuli"; Jean Piaget [1930] in the study of child development; Wolfgang Köhler [1940] using field theory; Kurt Koffka [19355] using Gestalt theory; its extension by James J Gibson [1967] into ecological psychology; and situated cognition [Slezak, 1995]. As shown by Dreyfus [2006] these and related cognitivist approaches are still shot through with strong reliance on information theory and representationalism for construction of explanatory models. Indeed the inventor and chief architect of the programmable serial digital computer, the backbone of artificial intelligence, John von Neumann [1958], realized early the limitations of the computer model:

> "Thus the outward forms of *our* mathematics are not absolutely relevant from the point of view of evaluating what the mathematical or logical language *truly* used by the central nervous system is. ... It is characterized by less logical and arithmetical depth than what we are normally used to. ... Whatever the system is, it cannot fail to differ considerably from what we *consciously* and *explicitly* consider as mathematics [pp. 81-82]."

Brain imaging also shows great promise as a source of new experimental data on global brain dynamics, but currently it is in a phase of empirical casuistry that in many ways resembles 19th century phrenology, owing to lack of adequate brain theory. Psychiatrists likewise rely heavily on empirical taxonomy following the failure of Freudian theory. Numerous proposals for theory have come from neurophilosophers on the one hand and from mathematicians and physical sciences on the other, but with inadequate experimental support and with derivations often too strongly Cartesian to meet the challenge. Therefore, the new techniques for acquiring macroscopic data and interpreting them on the light of updated field theory and neuropercolation theory can provide the solid conceptual structure that is necessary to solve the core problem of philosophy. There is more. Thomist/Heideggerian philosophy will likely lead to constructing a totally new class of machine, the intentional robot, which is based in neurodynamics instead of digital logic. This possibility is as relevant to philosophers as it is to engineers. If machine intelligence can comprehend and remember only the sensory consequences of its own intended actions, then it must be equipped with appropriate sensors, effectors, and sources of reward and punishment, and the ability to explore its environment with learning by trial and error under reinforcement. Demonstration of a solution to the core problem of philosophy by such modeling will require going beyond first intention, for which there is no realistic possibility at present, but solving the preliminary problem at the level of animal intelligence and first intention is sufficient challenge for the present generation.

9. Conclusions

From detailed measurements of the electric fields of the brain it is possible to infer that the essential operation in the sensory cortices is to replace stimulus input with constructs by the brain of conceptions that stem from anticipation based in memory. These constructs emerge by cooperative neurodynamics operating over a continuum of scales in time and space that can be divided into levels corresponding to the techniques of observation and measurement of brain activity and behavior. The constructs are states of knowledge that support predictions by multisensory projections from the present into the future of desired rewards through patterns of sensory input from the body and the environment. The anticipations exist as macroscopic patterns of neural activity that enslave the mesoscopic populations of neurons comprising the sensory and motor areas. In the sensory cortical areas the local attractor landscapes embody the specific predictions. The motor cortical areas embed the tactical trajectories of neural activity that control the movements of the body and shape the actions in the context of the changing environment. The changes in sensory inflow resulting from movements are transmitted to sensory cortical areas, where they encounter the attractor landscapes formulated through preafference. The sensory and motor mesoscopic activity patterns that exist in the forms and trajectories of the material substrate of neural activity are the abstract concepts that govern the engagement of the Dasein with the world by anticipating, acting, sensing, generalizing, and assimilating, encompassing first intention in animals and in preconscious states of humans.

In neurodynamics the process must be studied at multiple levels of its material substrate in brain, body and environment and the forms pertaining thereto. In physics the process must be described by models that combine the agent of action with that part of the environment that is engaged, creating a mirror image or ‘double’ in order to make sense of the unified system [Vitiello, 2001]. In philosophy the concepts referred to as phenomena constitute the mind, which directly enters into the world on its own terms, achieving closure and “maximum grip” without intermediation of representations or sense data [Dreyfus, 2006]. What is still inaccessible to analysis with respect to neurodynamics is an explanation of second intention, the experiencing of the world through awareness. There is no physiological test for consciousness above the elemental level of that imperfect reactivity, which is obtunded by anesthesia or sleep. There is only the phenomenological test of asking a subject, “What do you remember?” and comparing the answer with objective records. In the lack of such a test the only acceptable conclusion is that we do not understand yet the process of self-awareness. The aim of this essay is to describe a pathway into brain dynamics by experimental observation and measurement of the macroscopic fields of the brains of normal subjects, which will require devising and applying new and advanced EEG technology supplemented in parallel with related techniques of non-invasive brain imaging.

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