Osmetic Ontogenesis, or Olfaction Becomes You: The Neurodynamic, Intentional Self and Its Affinities with the Foucaultian/Butlerian Subject

Jennifer Ruth Hosek and Walter J. Freeman
University of California at Berkeley

Self, subject, individual, organism—other, object, society, world. Models abound, each with its theorization of the relationship between self and surroundings. In what sense does an organism perceive its environment? Do its genes and its world entirely determine its form? How can any autonomy that the individual has relative to her society be described? Here we compare contemporary models in which the self is defined as forming through embedding itself in its surroundings. In these understandings, an organism's ontology is not one of passive, static *being*, but rather one of *becoming* within its environment. Otherwise put, a self's ontogenesis is through that self's actions into its environment. Its ontology and its epistemology are intimately affiliated. The models of cultural theorist and historian Michel Foucault and feminist philosopher and cultural theorist Judith Butler arise as prime examples of this position. We describe another such dynamic model of the self now emerging through brain science, and focus on certain portions of Foucault's and Butler's varied work to demonstrate some affinities between these neurodynamic and postmodern models of self.[1]

Our neurodynamic model resonates remarkably with a wide range of philosophers, including Thomists working with the Aquinian doctrine of intentionality through active perception; the pragmatists, beginning with Charles Peirce and including William James

1. For a particularly compelling collection of essays articulating links between scientific and literary theory, see N. Katherine Hayles, ed., *Chaos and Order: Complex Dynamics in Literature and Science* (Chicago: University of Chicago Press, 1991).

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and John Dewey; developmental psychologists such as Jean Piaget and Esther Thelen; Gestaltists such as Kurt Koffka and Wolfgang Köhler; their successors, the ecological psychologists, such as James Jerome Gibson and Michael Turvey; the Russian neuropsychologists Nicholas Bernstein and Alexander Romanovich Luria; the French neurophilosopher and phenomenologist Maurice Merleau-Ponty; and contemporary neurocognitive theorists such as Humberto Maturana and Francisco Varela, Timo Jarvilehto and Bernard Baars.[2] In this paper we explore two dynamic processes in particular in which the neurodynamic and the postmodern conceptualizations of self converge and resonate: the intentional arc of sensation-perception-assimilation/construction, and intentionality/resistance-agency. The goal of such comparison is not to collapse these models into each other, but to demonstrate their complementarity.

Our project assumes that scientific and humanist discourses can be fruitfully compared. Such work enriches each of these ways of knowing and enables us to understand more about the "cultural fields" that give rise to such similar and at the same time dissimilar narratives.[3] It also presumes that scientific models are not truths but intellectual tools;[4] they are metaphors.[5] Criticism that labels such

2. Thomas Aquinas, *Treatise on Man*, ed. Daniel J. Sullivan, trans. Fathers of the English Dominican Province, in *Summa Theologica*, vol. 19 (Chicago: Encyclopedia Britannica, 1952); Bernard J. Baars, *In the Theater of Consciousness: The Workspace of the Mind* (New York: Oxford University Press, 1997); Nicholas Bernstein, *The Coordination and Regulation of Movements*, trans. R. J. Drillis (New York: Pergamon Press, 1967); James Jerome Gibson, *The Ecological Approach to Visual Perception* (Boston: Houghton Mifflin, 1979); Timo Jarvilehto, "Efferent Influences on Receptors in Knowledge Formation," *Psychology* 98.9.41 (1998); Kurt Koffka, *Principles of Gestalt Psychology* (New York: Harcourt Brace, 1935); Wolfgang Köhler, *Dynamics in Psychology* (New York: Grove Press, 1940); Alexander Romanovich Luria, *The Man with a Shattered World: The History of a Brain Wound*, trans. L. Solotaroff (New York: Basic Books, 1972); Humberto Maturana and Francisco Varela, *The Tree of Knowledge: The Biological Roots of Human Understanding* (Boston: New Science Library, 1987); Maurice Merleau-Ponty, *The Phenomenology of Perception*, trans. C. Smith (New York: Humanities Press, 1962); idem, *The Structure of Behavior*, trans. A. L. Fischer (Boston: Beacon Press, 1963); Charles S. Peirce, *Chance, Love, and Logic* (New York: Harcourt Brace, 1923); Jean Piaget, *The Child's Conception of Physical Causality* (New York: Harcourt Brace, 1930); Esther Thelen and L. B. Smith, *A Dynamic Systems Approach to the Development of Cognition and Action* (Cambridge, Mass.: MIT Press, 1994); Michael T. Turvey, "Coordination," *American Psychologist* 45 (1990): 938–953.

3. N. Katherine Hayles, *Chaos Bound: Orderly Disorder in Contemporary Literature and Science* (Ithaca, N.Y.: Cornell University Press, 1990).

4. Michel Foucault, *The History of Sexuality: An Introduction*, trans. Robert Hurley (New York: Penguin Books, 1978).

5. George Lakoff, *Women, Fire, and Dangerous Things: What Categories Reveal about the Mind* (Chicago: University of Chicago Press, 1987); Peter Weingart and Sabine Maasen,

understandings of science inappropriate often rests on a belief in science as articulating a positivistic relationship of mental concepts to "reality." The world of objects is imagined to be ordered in accordance with fixed laws, and the task of science is to discover these eternal truths—truths such as the orbit of planets, and the laws of gravity. Our project seeks to replace this "truth" model with an understanding of science as a collection of tools with which we can engage our world and make of it our home.

In our essay we will first outline our neurodynamic model[6] of the intentional self,[7] using the example of sensation/perception in olfaction. Then we will show the parallels of our model with Foucault's and Butler's models of the subject.

Conceptions of Sensation/Perception in Context: Competing Models

In our system, an individual is defined as a biological intentional structure acting into the world. Sensation/perception plays a crucial role in the individual's becoming by virtue of intentionality. Intentionality is a constructed notion designating a biological process in which an organism with a central nervous system that includes a forebrain complex enough for the organism to construct its own history uses this history to contextualize its actions and to engage in behavior based on prediction of its future from its experience. Since the definitions of sensation and perception are debated in contemporary scientific circles, it is useful to contextualize the specific definitions we are using here. What follows is a brief description of the *empiricist* and *intellectualist*[8] approaches to conceptualizing sensation/perception, and the intractable problems inherent in each method.

"The Order of Meaning: The Career of Chaos as a Metaphor," *Configurations* 5 (1997): 463–520.

6. We collaborated by Freeman performing wet laboratory work and computer modeling and Hosek linking the results to contemporary theory.

7. In our work on animals we use the terms "self," "individual," and "organism" relatively interchangeably. This linguistically represents the conception of the human as part of a continuum of animal evolution, and enables extrapolation between animal models—for example, from tiger salamander and rabbit to human.

8. Both of these terms have varied and contested definitions. Here, our definition follows Merleau-Ponty's 1947 critique of these two groups and his suggestion to label the third way "existential": Empiricists, the precursors of scientific materialists, have a deterministic, behaviorist conception of the mind as nothing but an epiphenomenon; organisms are hierarchies of reflexes and activities of neurons. Intellectualists, also labeled idealists or cognitivists by Merleau-Ponty, are interested only in minds and conceive of the organism as a dualistic entity in which minds are abstract structures in-

Both the empiricist and intellectualist models define *sensation* as the primary process by which the organism's sense organs detect objects in the outside world via sense receptors, and import sensory forms by nerve pathways. These models define *perception* as the exercise of reason to interpret those forms. Examples include: the excitation of chemical receptors in the nose when a certain odorant chemical locks into these receptors (sensation), followed by the recognition of an odor (perception); and the excitation of visual receptors in the eye when light impinges upon them (sensation), followed by the identification of the visual features of the object from which the light came (perception). Empiricists describe the vehicle of the sensory forms as *information* that is processed, stored, retrieved, and combined in accordance with logic. Intellectualists describe the sensory forms as *representations* that likewise are imprinted from sense data, stored, recalled, and manipulated according to the laws of reason and emotion. In our model the vehicles of information and representation are replaced by the notion of *meaning*.

Based on this materialist theory of sensation, empiricists study single cells involved in sensation to see how and when these cells react to stimuli. Scientists such as David Hubel and Torsten Wiesel are well-known proponents of this approach. Their work on visual sensation, for example, involves shining a light across the retina to determine the range and location (receptive field) that activates a single neuron in the retina or in the visual cortex. They then correlate this pattern of firing with physical properties of the light that influence the firing, such as its motion, its size, or its intensity. This approach assumes that the elements of the outside world cause the firings deterministically without the receptor cells' say in the matter. Moreover, it implies one-to-one correspondence between elements of the surroundings and sensations believed to be caused by them.[9]

The approach of intellectualists is similar in that it also implies one-to-one, unidirectional correspondence between small bits of the outside world and neuronal firings, yet it differs from the empiricists' in two significant ways. First, it assumes preexisting conceptual categories in the brain. Researchers such as Horace Barlow and Jerry Lettvin, for example, who also study single neurons and their pulse frequencies (rate of firing), focus on correlating these firings with *fea-*

dependent of the platform in which they are materialized—be that platform of hydrocarbon or silicon. See Maurice Merleau-Ponty, *The Primacy of Perception,* trans. J. M. Edie (Evanston, Ill.: Northwestern University Press, 1963 [1947]), pp. 12–42.

9. David Hubel, *Eye, Brain, and Vision* (New York: Scientific American Library, 1995).

tures of the object in the outside world.[10] Neurons are labeled *feature detectors* and are believed to organize knowledge about the outside world into predetermined categories (features). These categories are reminiscent of Kant's a priori categories of knowledge, through which we gain empirical, a posteriori knowledge of the world. Subsequent researchers have conceived neurons as operating in vectorial sums (Apostolos P. Georgeopolis), attractors (Daniel Amit), chains (Moshe Abeles), networks (Yasushi Miyashita), and plastic groups (Miguel Nicolelis)—always using the same principles of subjective representations of observer-defined objects.[11]

The second important difference between these two schools is the intellectualists' notion that receptor neurons use representations to communicate the sensations they have registered to the mind. The language metaphor in Lettvin's germinal paper "What the Frog's Eye *Tells* the Frog's Brain" (emphasis ours) makes it clear that the authors believe that representations exist in the brain.[12] This model assumes, then, that the brain takes in sensations from the world, converts them into symbols, and manipulates them to understand and predict the world. This representationalist concept has led to the development of AI programs such as "expert systems," and the concept of information has led to neural networks such as "multilayer perceptrons," in the efforts of engineers to develop machine intelligence from an understanding of brain function. The variants of neural networks that putatively operate without "representation" in fact represent by using numbers. For instance, in neural network modeling, neuron firings are represented by numbers that are then fed into the neural network. The connections within the network operate upon these numbers to simulate sensation/perception. The connection weights—which represent the strengths of the synaptic connections in brains—change in response to inputs that produce certain out-

10. Horace Barlow, "Single Units and Sensation: A Neuron Doctrine for Perceptual Psychology?" *Perception* 1 (1972): 371–394; Jerry Lettvin et al., "What the Frog's Eye Tells the Frog's Brain," *Proceedings of the Institute of Radio Engineers* 47 (1959): 1940–1951.

11. Moshe Abeles, *Corticonics: Neural Circuits of the Cerebral Cortex* (Cambridge: Cambridge University Press, 1991); Daniel Amit, *Modeling Brain Function: The World of Attractor Neural Networks* (Cambridge: Cambridge University Press, 1989); Apostolos P. Georgeopolis, A. B. Schwartz, and R. E. Kettner, "Neural Population Coding of Movement Direction," *Science* 233 (1986): 1416–1419; Yasushi Miyashita, "How the Brain Creates Imagery: Projection to Primary Visual Cortex," *Science* 268 (1995): 1719–1720; Miguel Nicolelis, "Dynamic and Distributed Somatosensory Representations as the Substrate for Cortical and Subcortical Plasticity," *Seminars in the Neurosciences* 9 (1997): 24–33.

12. Lettvin et al., "Frog's Eye" (above, n. 10).

puts. Feedback mechanisms enable the comparison of observed outputs with desired outputs, and the differences between them are used to determine the directions of change in the numerical weights.

Despite these differences, both the empiricist and intellectualist classes of models have their intractable problems in explaining perception. Neither has been able to adequately explain the phenomenon of consciousness. While empiricist researchers such as Daniel Dennett state that brain activity simply *is* consciousness, his opponents disagree; John Searle, for instance, argues that firings of neurons cannot be identical with meaningful experience, while Roger Penrose asserts that explaining consciousness will require "new laws of physics."[13] These notions of mind cannot account for the goal-directedness of perception and the correlated subjective awareness of the outside world as secondary to intentional engagement.

A concrete example of this debate centers around *qualia*—qualities of a perceived object, such as the redness of a rose or the softness of velvet. These qualia are not inherent in the rose or the velvet; they exist in the minds of the observers. While the subject of qualia is difficult to address adequately with any model, unidirectional empiricist models cannot begin to account for this phenomenon that so obviously depends on interaction between the observer and the outside world. Arguably they cannot even explain how observers can be *conscious* of the rose or the velvet—a consciousness that we the authors believe *itself* depends on expectancy, or intentionally created specific states of excitability.

The empiricists and intellectualists must provide an answer to the "binding problem," also known as the "figure-ground" problem, but thus far they have not. How can the sensory input from the various feature-detector neurons be bound together in such a way as to represent an object and thus to bring it to consciousness? Why wouldn't it be bound differently? Why, for example, do we perceive a chair in our visual field as an object distinct from a table in the same visual field? We could just as well "bind" the input we receive into a "chairtable."

Empiricist-materialist and intellectualist accounts ultimately fail because they do not have an adequate formulation of the essential concepts of *intentionality* and *meaning*. For most contemporary ana-

13. Daniel Dennett, *Consciousness Explained* (Boston: Little, Brown, 1991); Roger Penrose, *Shadows of the Mind* (Oxford: Oxford University Press, 1996), quotation on pp. 7–8; John Searle, "The Mystery of Consciousness," *New York Review of Books,* November 1995, pp. 60–66; John Searle, *The Rediscovery of Mind* (Cambridge, Mass.: MIT Press, 1992).

lytic philosophers, intentionality denotes the relation between a mental representation and the object that it represents, thus invoking the Cartesian subject/object dichotomy and the intractable "symbol grounding" problem. A thought, belief, or remembrance is "about" something, hence the common use of the term "aboutness" to refer to intentionality. Similarly, information theory, which is a foundation on which much of artificial intelligence is built, begins by theorizing a separation of meaning from information and working only with the latter.[14] Yet an observer's perception of an object *is* the meaning of that object for the observer. Fried liver is not inherently "delicious" or "disgusting"—or even "fried" or "liver": those meanings arise from previous individual experience. Knowledge is epistemological *and* ontological. It is not based on preexisting representations or categories; rather, it is created through our actions into the world and our responses to the impact of the world upon us. There are no context-free rules that govern how symbols are manipulated in our minds; rather, any regularities that shape our knowledge and actions are learned through our interactions with the world, and they alter as we alter relative to the world by assimilating to the world. Input is not "bound," but instead leads to creations that are the meaning that the input has for an organism over a certain time—creations that are intimately related to how the organism is *becoming* over that time.

Our Dynamic Action/Perception Model

This brings us to the third approach to the question of sensation and perception, which we, at Merleau-Ponty's suggestion, call the *existentialist* school.[15] Here the results of experimental neurodynamics resonate with the works of pragmatists, enactionists, and phenomenologists such as those authors we have already cited. Sensation and perception in our terms rest on two basic assumptions. First, our model is monistic; it denies the mind/body dualism that underlies most of Western thought, including some of the best-known existentialist philosophers' theories, such as those of John Paul Sartre and Simone de Beauvoir. Mind *is* biological. This is not a reduction-

14. Claude E. Shannon wrote as follows: "The fundamental problem of communication is that of reproducing at one point either exactly or approximately a message selected at another point. Frequently the messages have meaning; that is they refer to or are correlated according to some system with certain physical or conceptual entities. These semantic aspects of communication are irrelevant to the engineering problem" (Claude E. Shannon, "A Mathematical Theory of Communication," *Bell System Technical Journal* 27 [1948]: 379, 623).

15. Merleau-Ponty, *Phenomenology* (above, n. 2), pp. ?? . Ed.: Page(s)??

istic or deterministic view: it is not that mind is "only" biology. Rather, the mind in all its multidimensional facets—its capacities for imagination, subjective apprehension of the world, and what humans call the sublime—is a biological process.

Second, in our view humans and all other intentional organisms are cumulatively shaped by our actions into the world. We say that minds are not baths of electrochemicals, nor are they collections of representations; we say they are actions into the world and these actions' sensory consequences. We will concretize this statement shortly. This conception radically departs from the common definition of sensation/perception. Not only does it take the *meaning* of the perceived object for the organism into account, it implicates sensation/perception in the formation and continuous reformation of the organism in the world. A familiar version of this concept is described by John Dewey's philosophical/psychological concept of the reflex arc, which he articulates as action *into* a stimulus rather than (re)action *to* a stimulus.[16] This formulation emphasizes the active relationship between sensation/perception and the formation of the organism itself. Another version is Merleau-Ponty's philosophical conception of the intentional arc: the organism acts into the world and seeks stimulation from the world, which shapes its future action into the world, in a *perpetua mobile* that is always searching for maximum grip, the intended optimal engagement of the body with its environment.[17]

Experimental neurodynamics leads to a biological model of Merleau-Ponty's philosophical conception and offers solutions to some heretofore-intractable problems in the existentialist project.[18] In particular, neurodynamics makes explicit a distinction between sensation and perception that was not available to Merleau-Ponty at the time he was writing. In his phenomenological, intentional-arc model the philosopher had to rely solely on activity that is already well into the perception stage, making it difficult for him to adequately theorize precisely how our ontogenetically unique perceptions could embody the fabric of both self and world.[19] Our neurodynamic elaboration of the distinction and interrelationship between sensation and

16. John Dewey, "Psychological Doctrine in Philosophical Teaching," *Journal of Philosophy* 11 (1914): 507–512.

17. Merleau-Ponty, *Phenomenology*, pp. ??

18. See Walter J. Freeman, *How Brains Make up Their Minds* (London: Weidenfeld and Nicolson, 1999); idem, *Neurodynamics: An Exploration of Mesoscopic Brain Dynamics* (London: Springer, 2000). Ed.: Page(s)??

19. Merleau-Ponty, *Phenomenology*, pp. ??

perception also enables an understanding of consciousness as a biological, rather than a metaphysical, entity. Without this distinction, existentialist models such as Merleau-Ponty's cannot fully address the question of consciousness without risking the charge of idealism. Our research results also mean that the existentialist model can finally address the question of self-organization. How is it that minds can act intentionally into the world through the creation of goals and object-oriented behaviors—or, biologically expressed, how can neurons create new patterns of activity that find expression in the sophisticated, spontaneous, playful, creative, often seemingly irrational behaviors that characterize intentional beings such as animals, adults, and small children?

A Neurobiological Model of Sensation/Perception: The Case of Olfaction

Let us use the example of olfaction to take a more detailed look at the mechanics of this existentialist conception of sensation/perception. There are several good reasons for doing so. The sense of smell was the first to develop in phylogeny, and it became the prototype for perception by vision, audition, and touch as well. The algorithms for olfactory perception were adapted to the receptors for light, sound, smell, and vibration, which also receive from a distance to give early warning and time for detection and identification. Although excitations of all of these senses combine to form multisensory percepts—gestalts—and to decide a course of action,[20] the olfactory system remains the simplest with respect to preprocessing in sensation. Study of olfaction thus offers the clearest access to study of the mechanisms of perception.

Let's begin at the cilia in the nose. When the olfactory molecular receptors connect with molecules in the air and activate, they send action potentials down their axons in an orderly array of parallel pathways to the olfactory bulb. Here they topographically map onto receptors in the bulb. There are about 100 million olfactory molecular receptors in the nose and only about 100,000 receiving mitral cells in the olfactory bulb, so the mapping is not strictly one-to-one, but convergent: in this case, a convergence of 1,000-to-1. This implies that even at this early stage, input that is not corroborated by other input will ebb away. The microscopic activity engendered by stimulation of the receptors and the bulb is *sensation*.

When this microscopic receptor input has reached the olfactory bulb and forced microscopic activity of the mitral cells, there is a

20. Koffka, *Gestalt Psychology* (above, n. 2); Köhler, *Dynamics in Psychology* (above, n. 2).

macroscopic destabilization over the entire bulb; that is, the activity in the bulb goes from a low-energy state to a high-energy oscillatory state. This global pattern of spatiotemporal oscillation is *engendered by* the input from the sensory receptors, but it is not a direct translation of the input. In other words, the oscillation is not imported from outside; rather, it is constructed *endogenously*, based on the prior synaptic changes that define and express the history, context, value, and significance (i.e., the meaning) of the stimulus for the organism at that moment in time. This step is the threshold of *perception*. It consists of abstraction of the intended figure from the background and generalization to assign it to an appropriate class that is selected by intention and that has been shaped by experience. Aquinas first described these considerations in his theory of intentionality: our knowledge of material objects and events, he wrote, must be created within ourselves.[21] This is obvious in olfaction. We cannot know the outside world or the pattern of action potentials in our sensory receptors with each sniff; we can only know what the bulb reports to our brain after it forms the macroscopic activity that constitutes abstraction and generalization.

The macroscopic activity of the olfactory bulb consists of this constructed global pattern of oscillation. The persisting microscopic activity is sensory-evoked activity initiated from the receptor input. Both the constructed global oscillation and the sensory-evoked activity are projected onto the olfactory cortex by means of a divergent projection, rather than the essentially parallel pathways between the receptors and the olfactory bulb. This divergent projection means that each neuron in the olfactory bulb transmits broadly to many neurons in the olfactory cortex. On the receiving end, neurons in the olfactory cortex receive converging input from many neurons in the olfactory bulb. Each receiving neuron sums the inputs it receives and fires action potentials based on this input via projection to other cortices in the brain.

Let us take a more detailed look at the activity in the olfactory cortex. In the cortical neurons' summation of the converging activity from the olfactory bulb, those inputs that are part of the bulb's global spatiotemporal oscillation pattern are the most influential in eliciting cortical neuron firings. This is the portion of the olfactory bulb's macroscopic activity that is constructed by the bulb in response to olfactory receptor impulses from the nose. At the neuronal level, this global oscillation corresponds to simultaneous firing patterns of olfactory neurons from all over the bulb. The outgoing ac-

Ed.: Page(s)?? 21. Aquinas, *Treatise on Man* (above, n. 2), pp. ??

tion potentials from the bulb that are part of the global oscillation arrive simultaneously at many cortical neurons, and the sum of this simultaneous input tends to exceed each cortical neuron's firing threshold. If the threshold is exceeded, the cortical neurons fire, sending action potentials in parallel projection out to other cortices. Action potentials from the olfactory bulb that do not share the common wave form are less influential because their erratic arrival at cortical neurons increases the possibility that their input is not significant enough to reach the neurons' firing thresholds. As with the noncorroborated receptor input to the bulb, these sensory-evoked action potentials arriving from the bulb to the cortex are not coherent, but asynchronous, and tend to be washed away or smoothed out. The synchronous activity that the olfactory bulb constructs, on the other hand, is influential in driving olfactory cortex activity. These findings are the basis of our conclusion that what the rest of the brain works with from the olfactory system is what has been created by the bulb in an intentional relationship with the surroundings—that is, by abstraction and generalization; in Aquinas's terms, the faculty of imagination. Notice that this cooperative dynamic enables and requires the emergence of a common wave form in cortical output with each destabilization.

As a metaphor for how this model works, we can imagine a group of people shouting. We just hear noise: asynchronous frequencies. But if some are shouting in a cooperative manner, that shared frequency is what gets through. The "shared frequency" that has been created by the bulb neurons in relationship with the surroundings and in concert with each other is what the rest of the brain works with from the olfactory system. This relationship of individuals with a population that has formed by virtue of these individuals' similar actions and interactions has been described in mathematical terms by theoretical physicists and chemists, and in linguistic terms by social philosophers such as Foucault.[22] We have found that the same basic rules hold for the dynamics of the visual, auditory, and somesthetic sensory systems. We believe that similar patterns emerge in relations between microscopic individuals and macroscopic collectives, as well as at all levels of the material and social worlds, giving an opportunity to seekers in many scientific and humanistic studies to learn from each other and expand their visions.

This biological finding in sensory cortices is fundamentally im-

22. Foucault, *History* (above, n. 4); Hermann Haken, *Synergetics: An Introduction* (Berlin: Springer, 1983); Ilya Prigogine, *The End of Certainty: Time, Chaos, and the New Laws of Nature* (New York: Free Press, 1996).

portant in all theories of perception. What it says is that after sense data have made their contribution to the construction, modification, and selection of oscillatory patterns of neural activity, they are washed away. The sense organs express all contacts with the environment in action potentials, which have no spatial form or temporal continuity. There is no transfer of forms by which to make internal representations, no sequencing of trains by which to process information. There is direct contact with the world, but not by the intellect, only by the sensory cortices that receive the action potentials. This is the basis for our invocation of the notion of "epistemological constructivism."[23] Everything that we know about the world has been constructed within our brains—yet equally fundamentally we are engaged with the world in such intimacy that we *are* by our ceaseless interactions with our world. Our explanation of this seemingly paradoxical engagement is to be found not in the sensory systems, but in the intentional and motor systems of our brains.

Sensation/Perception and Intentionality: The Case of the Tiger Salamander

The model of sensation/perception thus far is a biological description of first intention. Second intention requires the integration of multiple sensory inputs into gestalts, and the organization of gestalts into the flow of experience. In order to make this next step explicit, let us talk about it using the example of a tiger salamander. This animal is ideal as a subject because its anatomy is relatively simple and it is considered to be the closest surviving relative of the ancestor of all vertebrates. The tiger salamander's aggressive, adaptive, goal-directed behavior also makes it a prime candidate in the discussion of intentionality.

The tiger salamander has a small, compact brain. It has two cerebral hemispheres comprising its forebrain, which converge into a

23. In previous work one of us (WJF) uses the term "epistemological solipsism" to describe the process by which knowledge is created through actions into the environment. This process is imposed by the sense organs' operations as they interface with the material world, and it constitutes a barrier between the finite capabilities of the organism and the infinite complexity of its surround. The term "solipsism" has the unfortunate connotation for many readers of isolation of the individual from its world, commonly seen as positing the world as nothing more than a dream. In this text we follow Ernst von Glasersfeld by using the term "constructivism" to describe the manner in which brains create unique understandings of the milieus with which they deal; see Ernst von Glasersfeld, *Radical Constructivism* (London: Falmer Press, 1995). We also use the term "bio-epistemological uniqueness" to describe this conception, in order to highlight the biological and subjectively felt nature of this way of knowing and of becoming.

midbrain, then converge into a hindbrain from which the cerebellum and spinal cord extend. Axons from receptors in the nose project onto the anterior third of the surface of the two hemispheres, where the olfactory bulb, part of the cerebral cortex, is located; thus there is a direct pathway that receptors, with their cilia extending into the outside world, form by sending their axons directly into the cerebral cortex. The lateral third of the hemispheres contains the pyriform cortex, essentially a motor cortex with projections going down into the brain stem with relays into the spinal cord. The medial third is a well-developed laminated neuropil that we call the primordial hippocampus. Located between these three areas is a transitional cortex that receives input by way of the thalamus from all sensory systems except the olfactory (whose input goes directly to cortex in the manner described above). Visual, auditory, somatosensory, gustatory, and olfactory input converges in the cerebral cortex.

Thus we have the sensory cortex, the motor cortex, and the association cortex (which in the salamander is the primordial hippocampus); they are bidirectionally connected with each other so that they are interactive, each transmitting to the others and receiving from the others. These three elements—sensory, motor, and associative—have evolved throughout the vertebrate phylogenetic evolution. This exceedingly basic system has continually undergone modifications and elaborations, both ontogenetically in individuals and phylogenetically across species—particularly the associative system with the hippocampus as its centerpiece, which becomes the limbic system. The most complex limbic system of any species in the animal kingdom is in humans; to understand it, we must study simpler systems.

How does this intentional system function in sensation/perception? Let us consider the problem of converting sensation into perception in olfaction using a scenario of a hungry tiger salamander searching for food. In this description we will focus on how the olfactory bulb is destabilized, as a model for how the larger limbic system can be destabilized to give rise to the integration of goal-directed behavior; we still have inadequate knowledge to be able to describe exactly how these active states emerge in the entire organism. Note that these processes are expressed in causal terms, although our model contests "causality" in its usual definition.[24]

24. Our model contests the existence of causality except as a societal construction: see Walter J. Freeman, "Consciousness, Intentionality, and Causality," *Journal of Consciousness Studies* 6 (1999): 143–172. We use causality here as a semantic tool. Similarly, this paper and the research that it describes rely on various types of categorization. These categories should not be conceived of as absolutes. It is our position that understand-

Moreover, this is a circular model, by which we mean that in the explanation that follows, although we begin at the chicken, it is just as valid to start at the egg.

So we have a hungry tiger salamander with a state of arousal directed to the pursuit of food. The salamander is not moving, but some odorant molecules of a food source fall onto its receptors. These molecules cannot yield the location of the food, but only their time of arrival and their specificity based on which receptors they have activated. These latter expressions are carried into the animal, via the receptors' spatial patterns of activation: to the olfactory bulb, then to the olfactory cortex, and so on.

Based on its perception of the odorant, which includes of course its state of arousal and all its previous experiences—with the particular odorant, with being hungry, with searching for food, and so forth—the salamander acts intentionally into the environment. In our scenario, it decides to explore. It moves forward and takes another sniff sample to find out whether the odor is stronger or weaker. In order to make the distinction between stronger and weaker, it must retain a sample strength in the form of an active state of brain activity that registers the construction initiated on the first whiff. The salamander compares the active state registering the second whiff with the previous active state registering the first.

Now the difference between the two whiffs has no meaning unless the animal knows quite a bit more. First, it must know where it was when it perceived the odorant the first time, and where it is when it takes the second whiff. It also must note what it did between whiffs. This meaning involves, then, other forms of input. For example, the salamander initiated a motor command that went into the muscles and the joints and resulted in movement. Proprioceptive pathways then fed the resultant movement from the body back into the brain. This proprioceptive activity essentially tells the animal whether in fact the commanded motion has taken place, and if so, with what result.[25] It has input from its eyes and ears that tell it whether it moved, in which direction, how far, and so forth.

ing the constructed nature of causality and categories does not preclude their use in conceptual models.

25. By definition, input that comes back from the outside world is *exteroceptive*. Input that comes from within the body is of two kinds: *Interoceptive* input is the feelings you get from your gut—subjectively understood as "gut feelings"—and also from the blood vessels, the lungs, and other places where there are sensory receptors controlling the viscera. *Proprioceptive* input refers to input from the musculoskeletal system via the joint receptors and muscle stretch receptors. For the most part it feeds into the forebrain through the cerebellum. It always involves a loop outside the brain (thereby differing from reafference) but within the body (thereby differing from exteroception).

Further, the animal has to have some means of coping with the space in which it is operating, a picture that psychologists refer to as a "cognitive map." This is a metaphorical term introduced by Edward Tolman from his studies of rats' orientation abilities in mazes, from which he inferred they must have something like a "cognitive map" in their heads.[26] The salamander establishes such a "map" over time by exploring, as do all organisms. During such explorations, organisms build massive dynamic networks of neurons that have the capability of giving them position sense of where they are in their world, and where they move to in going from one stimulus to the next, depending on where they were and where they intend to go. The "map" is not a stored image or reference chart; it is a capacity to move appropriately without need for reflection.

What other elements are involved in the salamander's search? Most notably, whenever a signal is sent from the cerebral hemispheres in the forebrain to the hindbrain and spinal cord to initiate action, a copy of the signal is sent to the sensory receiving areas to prepare them for changes in sensory input flow that are consequent to the intended action. This process of distribution of signals for intended action is known as *reafference*. It is based on recurrent branches of axons carrying action potentials that are known as "corollary discharges." It is a form of feedback that plays just as important a role in the unity of perception as proprioception does, but this communicative activity occurs only within the brain, not through the body.

The reafference process was discovered about 120 years ago by renowned physicist and army surgeon Hermann von Helmholtz, who noticed a remarkable phenomenon in some of his patients with injury to the ocular motor nerve: if there was a paralysis of lateral gaze, the patients reported that when they attempted to move their eyes laterally, the visual field moved in the opposite direction. Helmholtz also observed that if a subject's eyeball was moved passively, the world appeared to move, which it did not if the subject moved his eye under intentional control. (You can try this if you press lightly on your eyelid: you will find that the visual world will appear to move.) On the basis of these experiments Helmholtz inferred that intentional output directed toward intentional eye movement—toward eye muscles, for example—also manifests a discharge from the motor centers into the visual cortex. This corollary discharge acts as the basis for distinguishing the movement of the visual field that is at-

26. See John O'Keefe and Lynn Nadel, *The Hippocampus as a Cognitive Map* (Oxford: Clarendon Press, 1978); Edward C. Tolman, "Cognitive Maps in Rats and Men," *Psychological Review* 55 (1948): 189–208.

tributable to the world's motion from the movement of the field that is attributable to a movement of eyes in the head.[27]

As shown by Helmholtz's observations, reafference occurs in concert with commands sent out from the brain. Think, for example, of our salamander. Imagine that a command for locomotion is sent out from its brain. The command initiates action both in the locomotor system and in the autonomic nervous system, which "backs up" the locomotor system by increasing heart rate, mobilizing glucose, and so forth. When this command with its multiple aspects goes out, a corollary message goes to the sensory systems in the brain, reflecting all aspects of the motor command and transmitting nearly simultaneously to the whole hemisphere. We cannot distinguish between such corollary discharge and activity received by the motor cortex for proprioception, nor can we separate out aspects of the discharge going to specific sensory cortices to prime them for possible results of the animal's search movements. Perhaps the attempt to distinguish these activities is artificial. The seemingly indivisible nature of the discharge emphasizes the interrelatedness of all the components in the chicken-and-egg circularity of this sensation/perception cycle. In light of this new understanding, we will henceforward label the cycle more accurately as the action-perception cycle and consider sensation to be an intermediate stage of perception, between action and understanding. Moreover, this action-perception cycle is intrinsically interrelated with the specific perceptions that occur and with the organism's alteration as a whole over time.

In further describing this process at the level of the organism, we can now show that perception is an intentional action into the world. Let us go back to the beginning of the hungry tiger salamander's tale. We can now see that the odorant molecules that fell upon its receptors stimulated the olfactory bulb in accordance with the

27. Helmholtz concluded that "an impulse of the will" that accompanied voluntary behavior was unmasked by the paralysis. "These phenomena place it beyond doubt that we judge the direction of the visual axis only by the volitional act by means of which we seek to alter the position of the eyes" (Hermann von Helmholtz, *Treatise on Physiological Optics*, vol. 3: *The Perceptions of Vision*, trans. J. P. C. Southall [Rochester, N.Y.: Optical Society of America, 1925], p.). J. Hughlings Jackson (1931) repeated the observation, but postulated alternatively that the phenomenon was caused by "an in-going current," which was a signal from the nonparalyzed eye that moved too far in the attempt to fixate an object, and which was not a recursive signal from a "motor centre" (John Hughlings Jackson, *Selected Writings of John Hughlings Jackson*, ed. J. Taylor, F. M. R. Walshe, and G. Holmes [London: Hodder and Stoughton, 1931], pp.). He was joined in this interpretation by William James and later Edward Titchener, thus delaying deployment of the concepts of neural feedback in reentrant cognitive processes until late in the twentieth century (William James, *The Principles of Psychology* [New York: H. Holt, 1893]; Edward Titchener, *An Outline of Psychology* [New York: Macmillan, 1907]).

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meaning of the stimulus to the salamander at that instant. Destabilization of the olfactory bulb—the onset of abstraction in perception—cannot occur in an environment of complete indifference on the salamander's part.

Three conditions influence whether the sensation will lead to meaning for the animal so that destabilization occurs and develops accordingly. First, the animal must become *aroused*. This is not to be confused with motivation, which consists of the conditions and reasons for a readiness to perform a specific action into the world. Arousal can be more closely paralleled with the human's subjective state of alertness. In neurochemical terms, arousal is an activation of the system that potentiates the increase in activity of the forebrain (including the olfactory bulb), the brain stem, and the spinal cord. This system of arousal is an interactive and cyclical process. It is mediated by the brain stem, and it "turns on" the brain to sustain rapid communication between all the different parts.

A second condition is a degree of *prior experience* with this molecule or with one perceived to be related. Manipulating the olfactory input to newborn rabbits illustrates this: The rabbits can be locked onto, learn to respond to, virtually any nontoxic odorant simply by smearing it on the nipple of the nursing rabbit so that when the infants feed, they develop an affinity for this odor. The young rabbits then will not respond to an odorless female, but will feed only when the odorant is present. We conclude that the bulb activity that the newborns exhibit when sniffing this odor is not an importation of the odor into the bulb. Instead, destabilization of the infants' olfactory bulb in response to the odor is related to their prior experience of nursing in the presence of this odor. Moreover, analysis of the experimental findings shows that some form of nerve-cell assembly must exist in order for the system to destabilize and give rise to a burst of activity. The development of a nerve-cell assembly is dependent on the neurochemistry of learning. In learning, connections are made and strengthened between nerve cells; these nerve cells then react in tandem when confronted with a familiar stimulus. In learning to respond to the odorant in this way, the newborns develop unique nerve-cell assemblies that link the odorant with feeding through the perception induced by the odorant.

The third condition influencing bulb destabilization is the *stimulus input to the aroused bulb from other receptor systems*. If an animal is hungry, for example, stimuli will be coming from the contractions of the stomach. Such input directs the bulb's active state into a certain pattern of oscillation. This is further evidence that the olfactory bulb's pattern of global oscillation is endogenous rather than an interior map of an external stimulus. Fried liver can mean "delicious food" if you are hungry enough, or if you have been appropriately acculturated.

More on the Role of Reafference in the Intentionality of Action-Perception: The Case of the Sniffing Rabbit

The tiger salamander model demonstrates the importance of reafference as a facilitating tool in the act of perception. Reafference primes the sensory cortex for the expected results of initiated body movements. This priming influences the probability and type of bulb destabilization. Let us focus on how this works on the level of the olfactory bulb by looking at reafference in action-perception. Remember that reafference is an intentional process. In olfaction, for instance, it is intentional with respect to the formation of olfactory-bulb activity bursts that occur sequentially with the intentional act of inhalation. Importantly, these bursts *do not* occur in a one-to-one pattern with each inhalation. This implies that the bursts are based on much more than sensory input from inhalation. Even more significant is that when an animal is challenged with the expectation that a stimulus will arise, some additional bursts occur which do not come from inhalation. We propose that they come from the limbic system out to the olfactory bulb as part of the process of reafference.

We can see this phenomenon clearly through work with a rabbit that is trained according to fixed intertrial intervals. The intervals are arranged so that every 12–60 seconds something occurs unpredictably: either a "go" stimulus, or a "no go" stimulus. If the animal is aroused, then it will expect that something is going to recur somewhere during this time interval. These controlled conditions offer a window of opportunity to observe the olfactory bulb closely in the last seconds before a stimulus arrives. There is often a pre-burst in the bulb before the "main event" burst that arises from the stimulus itself. We infer that this pre-burst occurs in response to activity coming from the limbic system out to the olfactory bulb: the limbic system is priming the bulb to receive a stimulus from outside the body via reafference.[28]

Expressed on the level of the bulb, this priming results in some modification of the bulb's attractor landscape. An *attractor* is the expression of a preferred state of a dynamic system, which is accessed when the system finds itself in, or is put into, an appropriate set of initial conditions. In these circumstances, the system will go to that

28. Leslie M. Kay and Walter J. Freeman, "Bidirectional Processing in the Olfactory-Limbic Axis During Olfactory Behavior," *Behavioral Neuroscience* 112 (1998): 541–553.

preferred state and stay there until otherwise perturbed. The set of initial conditions that directs access to that state is known as a “basin of attraction.” The term “attractor landscape” refers to the bulb’s set of possible preferred states, corresponding to the odors that it can identify, each with its basin of attraction and with its spatial pattern of amplitude. We might envision an attractor landscape as an undulating, morphing plane of marble holes in the childhood marble game of “potsies.” In our example, the pots are of different sizes, shapes, and depths, corresponding to the differences in attractor activity. They represent the shifting of attention between the learned states—the meanings and classifications—of the organism’s perceptions of its environment. Simultaneously, they represent a portion of the ontological *becoming* of the animal. This landscape is constantly in flux relative to the organism’s relationship to its surroundings. When the animal learns to identify a new odor, a new basin forms and all of the preexisting basins change, so that the changes in each basin affect the entire landscape; there are no edges to experience.

The priming of the bulb is the example of attractor-landscape modification that concerns us here. This modification, as well as the energy of the habituated background excitation, facilitates the attainment of an appropriate basin of attraction even with only a weak exteroceptive stimulus. The nerve-cell assembly’s reafferent activity shapes the landscape to enhance a desired basin of attraction, and the incoming stimulus, if appropriate, guides the system to that basin of attraction. Thus even if the input is relatively weak, the reafferent activity can alter the landscape so that the desired basin is created or access to the desired basin is facilitated. This process of reafference is closely tied in with the activity of all structures involved in perception, because all sensory/perceptual systems feed into the limbic system, whence come the corollary discharges. Thus the stimuli that arise from the olfactory environment contribute to the priming of all other sensory cortices, and vice versa. The slightest smell of smoke leads us to look for fire and listen for an alarm.

Reafference and Perception: Construction and Assimilation

In order to expand on reafference and perception, let us make another sketch of brain architecture, reafference, and the action-perception cycles—this time for the more complex mammalian brain that includes the neocortex. This strip of entorhinal cortex is a key structure in mammals, because all sensory cortices feed into it and receive corollary discharges from it.

In mammals, sensory systems feed into the entorhinal cortex by multiple relays, where the activity is combined. The patterns that come from visual, auditory, and somatosensory cortices have the same basic characteristic as the olfactory patterns: modulation of the amplitude of the common chaotic waveform. The entorhinal cortex sends most of its output into the hippocampus via the perforant path; thus it is the main source of input to the hippocampus. The hippocampus then sends most of its output back to the entorhinal cortex, and sends the remainder into the brainstem. That the activity takes this circular pathway implies that there is some form of time integration (the "short-term memory") as well as spatial orientation (the "cognitive map") going on, but the critical point is that this activity is the basis for multisensory integration into gestalts.

The entorhinal cortex sends output to three other targets. The first target is devoted to *autonomic motor activity:* the septum and hypothalamus. Via multiple descending pathways called the "medial forebrain bundle," the septum and the hypothalamus govern the autonomic systems, such as the cardiovascular respiratory system and the endocrine system, that "back up" intentional motor behavior. This outflow alters these autonomic systems' activity levels to suit a particular intentional activity *before* the latter is undertaken. Athletes, for example, show an increase in heart rate prior to the onset of a 100-yard dash. Gourmets show an increase in salivation as they sit down to a meal. These conditioned reflexes in anticipation of the events show that intentional actions incorporate the autonomic and neuroendocrine foundations of behavior.

The other two targets are the motor and sensory apparatuses, which the entorhinal cortex primes in anticipation of input. The *motor apparatus* organizes the musculoskeletal system's activity patterns and is found in the basal ganglia, linked to the brainstem and spinal cord by pathways that in lower animals are called the "lateral forebrain bundle." The term *sensory apparatus* refers primarily to the sensory cortices. The motor and sensory systems also feed back into the entorhinal cortex as intrinsic parts of the action-perception system.

We propose that this intentional system corresponds to what Merleau-Ponty calls a "transcendental field," which we understand as the organism and that portion of the world with which it is interacting at some specific time in the process of achieving "maximum grip."[29] To review briefly: A stimulus arrives when the animal has initiated a goal, in this case a search to bring the stimulus into a prepared brain state. The limbic system participates in determining the

Ed.: Page(s)?? 29. Merleau-Ponty: *Phenomenology* (above, n. 2), pp. ?; *Structure of Behavior* (above, n. 2), pp. ?

animal's goal. The limbic system's involvement is manifested in bulb destabilization and in that the bulk of the incoming activity goes into an appropriate basin of attraction. The desired stimulus activates, destabilizes, and gives access to the perceptual attractor. The attractor gives rise to a spatial pattern of oscillation that is transmitted into the motor cortex and into the hippocampus. This input functions as the basis for updating the intentional state—that is, updating the future of what the animal is going to do about and with this new content. So this burst of perceptual activity is pregnant with meaning relating to the past history of the organism and the immediate context of arousal and directedness. The learning that takes place at the close of each action-perception cycle serves to adapt the organism to its surround, a process that Aquinas denoted as "assimilation" (*adequatio:* i.e., toward equivalence).[30] Thus in our model, perception is a form of intentional action into the world, and sensation an intermediate stage of this cycle prior to conscious learning.

In our model, understanding the intentional nature of perception as action in respect to continually evolving goals, whether or not consciously perceived, resolves the seeming contradiction between the bio-epistemological isolation[31] imposed by the sensory receptors' reduction of the infinite complexity of sensory input to finite trains of action potentials, and the overwhelmingly obvious engagement that we all experience with our world. To be sure, there is an inside and an outside for each individual, but that dichotomy does not invoke the subject/object duality that characterizes Cartesian philosophy and its derivatives relying on representationalism, by which an internalized form of activity serves as a subjective symbol or signifier of an external object. In pragmatism, the inner states are intimately shaped through the consequences of intentional actions. Yet more needs to be said about the biological nature of the individual that posits itself in distinction from its surround and from others like itself, and in this we rely heavily on the views of Aquinas regarding the unity and wholeness of the intentional self.

Implications for a Model of the Self

We now can see that perception is the process by which the self assimilates itself to its environment, building its unity and wholeness. "Unity" refers to the state of being in the world at each point in time; "wholeness" refers to the lifelong trajectory of these moments of being. Perception has the property of unity: it is connected

30. Aquinas, *Treatise on Man* (above, n. 2), pp. ?

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across all sensory modalities and unified across experience. Successive frames of input combine into a lifelong trajectory through a laying down of synaptic connections in the process of learning. The whole of experience is available at all times with each new sensory/perceptual frame. The relative importance of previous actions changes, but there are no compartments, divisions, or edges in experience. All past experience is brought to bear upon every new action into the world. This can also be expressed by saying that every perception incorporates the whole of the individual in the world. The individual is the sum of her experience into the world; she is shaped by her actions into the world; she becomes through her actions into the world.

An intentional organism's development is not free in the Sartrian sense; rather, certain environmental and genetic influences define a background of potential with large-scale course limitations, limitations that gain their very meaning from the larger web of meaning. According to these logics, pups become dogs, kittens become cats, children become adults. It is within the framework of these large-scale boundaries that an organism acts into the world and develops *in pre-action and response to it*. There is no absolute freedom; rather, there is a degree of possibility, of potentiality, that can be realized with each step.

Within this fabric of possibilities, the individual's self-organizing dynamics in intra-action[32] with its environment modulate the direction in which growth occurs. Actions into the world, including perceptions, develop in accordance with the teleology of these dynamics. The quality of wholeness incorporates the organism's intentional teleology: the imagined form of its trajectory, and its sense of unity. Perception both reflects this unity and wholeness and forms them. Awareness and consciousness emerge only at the latest stages of perception, when the sensory and perceptual consequences of intended actions are being evaluated and the updating of the self is taking place through learning. In other words, the "operator of consciousness" appears only in the stage of *updating* the body about meaning that constitutes the self, not at the stage of *initiating* action.[33] In this

32. We use Karen Barad's helpful term here: Karen Barad, "Getting Real: Technoscientific Practices and the Materialization of Reality," *Differences* 10:2 (1998): online version. We will also use the term "assimilation" (see below, n. 36) to describe the relationship between organism and environment when we mean to focus attention more closely on the organism within this nexus.

33. This feature of brain dynamics illuminates the difficulty faced by phenomenologists attempting to understand the components of perception when all they have access to through their awareness is the last stage of synthesis.

sense, the feeling that one's vaunting conscious self is in control is an illusion; it is one's intentional self that initiates (re)action.[34]

In our view the biological self is engaged for survival in the task of coping with an infinitely complex environment using finite resources: its body with its senses and limbs, its compendium of experience, and its capacity for continual self-alteration in assimilating to its environment. It does not allow direct penetration of the forms of matter in which it is thrown for the material reason that its sense organs transmit only action potentials, and for the ontological reason that the forms received are innumerable and unclassifiable. Direct penetration would lead to "one big blooming confusion" of the kind that confronts adult individuals who are given sight or hearing for the first time via surgery.[35]

Two analogies are helpful here. Biologically speaking, perception resembles digestion in that the forms of foods are broken down before absorption, and the parts are reassembled into complex macromolecules that are unique to the individual.[36] The bio-epistemological barrier also resembles the immunological barrier; indeed, immunologists today face conceptual problems in defining the immune self that are comparable to those faced by neurobiologists in defining the cognitive self. During most of the twentieth century the

34. See Walter J. Freeman, *Societies of Brains: A Study in the Neuroscience of Love and Hate*, ed. Harold Szu, International Neural Networks Society Series (Hillsdale, N.J.: Lawrence Erlbaum Associates, 1995), 52–53.

35. William James, *Psychology: Briefer Course* (New York: Collier Books, 1962), p. 29.

36. Jean Piaget discerned the biological basis for knowledge: "no behavior, even if it is new to the individual, constitutes an absolute beginning. It is always grafted onto previous schemes and therefore amounts to assimilating new elements to already constructed structures (innate, as reflexes are, or previously acquired)" (*Biologie et Connaissance [Biology and knowledge]* [Paris: Gallimard, 1976], p. 17). Von Glasersfeld amplified this conception: "Piaget borrowed the word 'assimilation' from biology. If someone eats an apple, one might say: His body is assimilating the apple. This does not mean that the apple is somehow modified to fit into the organism's structure, but it means that only certain chemical components of the apple are recognized as useful and extracted by the organism, while all others are ignored and thrown out. In the biological model, therefore, assimilation does take in elements of the environment—nutrients or other chemical substances. In the theory of cognition in which Piaget adopted the term, this is not so, because the operative processes are not physical transfer but perception and/or conception. Once this is understood, the picture we get is quite different from the traditional one in which the senses are 'conveying information or data into the perceiving organism.' Using Piaget's definition, one can say: The cognitive organism perceives (assimilates) only what it can fit into the structures it already has. This, of course, is a description from the observer's point of view. It has actually the important implication that when an organism assimilates, it remains unaware of, or disregards, whatever does not fit into the conceptual structures it possesses" (von Glasersfeld, *Radical Constructivism* [above, n. 23], p. 63).

dominant view conceived the self as a fortress constantly embattled by invaders, with sentries posted to detect "non-self" chemical species and mount counterattacks based on information derived from analysis of the antigens. More recently the immune system has come to be seen as an ancient internal signaling device used to coordinate the various organ systems.[37] This system has been adapted to establish interactive contextual relations with a chemical world that vastly transcends in complexity the capabilities of any immune system to detect, identify, and comprehend the component.[38] The parallels between the immune self and the cognitive self in respect to olfaction and taste are particularly obvious. Generalizing to all of the senses in the formation of gestalts enables us to appreciate the magnitude of the tasks of coping with and assimilating the world, and to appreciate also the magnificence of the systems that have evolved to accomplish these tasks so successfully.

Postmodern Conceptions of the Subject

Modernist conceptions of the subject posit an individual separate from, and autonomous in relation to, his surroundings. For example, René Descartes's "cogito ergo sum" postulates a distinct self that knows itself and the world as a distanced observer. This view has been called into question over the centuries, recently by postmodern thinkers like Michel Foucault. For example, Foucault's genealogical historical projects claim that subjects in a given episteme perceive reality relative to the contemporary discursive norms and power relations.[39] Furthermore, for Foucault the individual himself is constructed by and in power.[40] *Power* is a diffuse and variously defined term that can be understood as a quality of relations between and

37. John Stewart, *The Primordial VRM System and the Evolution of Vertebrate Immunity* (Austin, Tex.: R. G. Landes, 1994).

38. J. Stewart and F. Varela, "Exploring the Meaning of Connectivity in the Immune Network," *Immunological Reviews* 110 (1989): 37–61.

39. Michel Foucault, *The Order of Things: An Archaeology of the Human Sciences* (New York: Vintage, 1994). An episteme is the particular field of possibility that enables certain perceptions and understandings rather than others. It bears similarities to Hayles's conception of cultural fields: see *Chaos Bound* (above, n. 3). Foucault's conception of the possibility of quick shifts from one episteme to another is analogous to Thomas S. Kuhn's paradigm shifts in *The Structure of Scientific Revolutions* (Chicago: University of Chicago Press, 1962).

40. Foucault and Butler are primarily concerned with the subject in discourse, and secondarily with the individual in society. The subject is a placeholder, a position that can be inhabited by an "actual" person, an individual. "Discourse" here can be broadly understood as all modes of cultural understanding and communication. Butler's insistence that these modes are all linguistic can be understood in the context of the general

within subjects that tends towards enabling changes that accord with a given society's norms. Power is heterogeneously and sometimes aporetically expressed in institutions, rules, and laws, as well as in societal conventions and, importantly, in a subject's own desires, fears, ideals, and beliefs. These discourses surround us and must be understood as forming our selves: creating us as subjects. Thus our very subjectivity cannot be understood as separate from the environment, or as autonomous in the modernist sense.[41] Such a conception raises many important questions. If the subject is constructed within his environment, what is the boundary between the two? Further, is an individual determined by these discourses, or is there an element of self-determination—that is, can agency be imputed to individuals? This is the crux of our discussion in what follows.

Postmodern Affinities—Subjects: Foucaultian, Butlerian, Neurodynamical

Foucault's and Butler's conceptions of the subject share some important similarities with our conception of the organism in the world. These similarities can only be seen if we are willing to compare across terminology. Furthermore, we must reformulate the categorical distinction between humans and nonhumans and instead see humans as organisms with certain characteristics that we perceive *by convention* to be qualitatively different from those of animals. This is a nonreductionist, monist model; we are not *only* or *just* biological organisms; rather, we are *completely* and *fully* biological organisms. In this understanding of organisms, a distinction is made between organisms with intentionality and organisms without intentionality. Following this classification enables analogies to be made between Foucault's and Butler's and our understandings of the self. It also enables a loosening of the anthropo-hierarchic viewpoint that has plagued much of Western thought.

The Foucaultian, the Butlerian, and the neurobiological models preclude the subject/object dichotomy. They insist instead on what John Haugeland calls the "intimacy" of mind and world.[42] However, in each of these models it is conceptually useful to consider self and world as two facets of one entity. For Foucault and Butler, the self's

"linguistic turn" that much of philosophy has taken. We must, for comparative purposes, use "subject," "individual," and "organism" interchangeably; we will, however, attempt when possible to use the vocabularies that the particular texts that we are treating prefer.

41. Foucault, *History* (above, n. 4), pp. 98–101.

42. John Haugeland, "Mind Embodied and Embedded," in idem, *Having Thought* (Cambridge, Mass.: Harvard University Press, 1998), pp. 207–237.

apprehension of her environment is always constituted by her unique subjectivation within the environment. Yet, simultaneously, that subjectivation—that forming of her as subject, that forming of her subjectivity—engenders an apprehension of the surroundings that is itself distinctive.[43] The self is uniquely bio-epistemologically constructed through intra-action with its environment.

Our neurodynamic model of olfaction represents this situation. The organism does not directly perceive the impact of chemical odors from its surroundings on its receptor cells; rather, its unique perception consists in its *prediction and hypothesis-testing* into these surroundings. All that the animal perceives is the specific outcome of the tested hypothesis, and the activity of perception is formed in assimilation with the environment, which includes the organism's state prior to and concurrent with the odorant impinging upon its receptors. These states consist in a variety of discourses, including the organism's alertness, past experience with the odorant and all other aspects of its surroundings, and so forth. We can say, for example that a rabbit's desire for a particular odorant is constructed within the discourses of the laboratory via the previously described odorant-training of newborn rabbits. Similarly, another organism's desire for a certain cologne might be formed within advertising strategies that link particular scents to sexual pleasure and desirability. These desires correlate to brain states; thus, expressed in neurobiological terms, discourses form the shape of brain activity, its material substrate, and the emergence of intentionality in masses of living neurons. The odor's meaning for and its very perception by the organism depends on these various factors, and this meaning and perception concomitantly shape the organism.

Temporality is also a key factor in subjectivation, as Butler demonstrates in her conception of the (re)articulation of the subject in power. This rearticulation is similar to Foucault's subject formed in and of discourses of power, and emphasizes more explicitly that, over time, rearticulation leads to change in the subject. Using neurodynamic categories to talk about the organism in conjunction with Butler's rearticulation offers a model that works for all intentional organisms. It delineates a biological model of Foucault's and Butler's philosophical models.

In our intentional-arc model of the organism's relationship with the world, the organism changes over time in intra-action with its surroundings. Its physical form and its intentional behavior are shaped and elaborated via this mediated relationship in ontogenetic

43. Judith Butler, *The Psychic Life of Power Theories in Subjection* (Stanford, Calif.: Stanford University Press, 1997).

development. An example is the common experience in second-language acquisition of only gradually being able to perceive and create nuanced distinctions between linguistic sounds that are not part of one's first language, and the differently strengthened musculature that results from incorporating these new sounds! Such ontogenetic alteration of an organism occurs within environmental discourses.

Our models also bear similar implications for conceptualizing consciousness. Explicitly in our model, and less explicitly in Foucault's and Butler's models, consciousness is not transcendental: it is constructed within discourses, part of the flow of self through the environment, creating the fabric's wholeness over time.[44] In each of these models, that which one might label the "conscious self" is theorized to be only illusorily convinced of its autonomy as an instigator of action and holder of opinion. Foucault's and Butler's notions of constructed subjectivity demonstrate that the subjective sense of autonomous self that a subject may herself hold is always already constructed and therefore cannot be considered autonomous in any traditional sense. In their work, subjectivity is part of the wider, discursive fabric and should be conceptualized within a different logic altogether—a logic that does not rely on hierarchies of autonomy, but rather on webs of imbrication, implication, and intra-action. The subject itself cannot exist without being called into being by formative discourses. Our neurodynamic model explicitly demonstrates, based on laboratory experimentation, that the "operator of consciousness" is not the driver of action into the world.[45]

Because each organism is uniquely constructed, it is impossible to understand all of the meaningful aspects of other organisms' physical and behavioral changes and these changes' interactions within these organisms; we cannot become another's subjectivity, much though this subjectivity may strongly shape our own. However, all three models enable us to assume correlations between the changes of others and our own internal states. Modernist, dualist models that

44. On page 18 of *Psychic Life*, Butler notes that "Foucault is notoriously taciturn on the topic of the psyche" and she seeks to remedy this, first offering a reading of the development of consciousness in Hegel's master-slave narrative in order to then argue that "[i]n [this] case, power that at first appears as external, pressed upon the subject, pressing the subject into subordination, assumes a *psychic form that constitutes the subject's self-identity*" (p. 3, emphasis ours). We read this to mean that, for Butler, there is no metaphysical interiority. Both Foucault's and Butler's relative reluctance to focus on consciousness is due in part to their skepticism concerning psychoanalysis, and in part to their concerns over raising the specter of dualism. Neurodynamics shores up their work by offering an explicitly nondualist model of consciousness.

45. Walter J. Freeman, *How Brains Make Up Their Minds* (New York: Columbia University Press, 2001), pp. 135–137.

would refute such intra-active correspondences rely on transcendent models of consciousness, personality, or subjectivity.

Postmodern Affinities—Populations: Foucaultian and Neurodynamical

We find a useful parallel between Foucault's view of how power discourses form societal subjects and our conception of how neurons combine their activity in creating the intentional states of whole brain function. We label the latter *Neuroactivity* in order to encompass the full range of its material forms and manifestations—electrical, magnetic, chemical, and microstructural. In this analogy we see that the system's elements are intradependent. Thus, subjects are formed in and form Power; neurons create and are created by Neuroactivity:[46]

> The analysis by Michel Foucault (1976)[47] of *power* and the emergence of *knowledge* in the context of society provides a useful analogy through which to understand the nature of Neuroactivity and the emergence of intentionality in masses of neurons. He writes that by power he does not mean state sovereignty, law, police, courts and armies (analogous to neural connections, transmitter potencies, electric currents, etc.), for these are "the terminal forms that power takes." Power (and Neuroactivity) must be understood "as the multiplicity of force relations immanent in the sphere in which they operate and which constitute their own organization; . . . as the support which these force relations find in one another, thus forming a chain or a system . . . , and lastly as the strategies in which they take effect, whose general design or institutional crystallization is embodied in the state apparatus" (pp. 92–93). So Neuroactivity arises initially in the developing brain in the absence of mature structure, and thereafter structure (connectivity) is shaped by activity as much as the converse, giving the Neuroactivity-intentional structure duo that is a counterpart to the power-knowledge duo. He advances four rules as "cautionary prescriptions" rather than as "methodological imperatives" (all quotes from pp. 98–101):

1. The "rule of immanence" advises starting from "local centers" of power-knowledge, which he conceives as pairs and groups of actants and reactants, and which have their parallel in pairs bound by synapses and masses of neurons, a "society of cortex."

2. The "rules of continual variations" mean that "the 'distributions of power' and the 'appropriations of knowledge' never represent only instantaneous slices taken from processes"; they are "'matrices of transformations,'" that are analogous to Neuroactivity patterns

46. The following extract is from Freeman, *Societies of Brains* (above, n. 34), pp. 52–53.

47. Foucault, *History* (above, n. 4).

that evolve by serial state transitions resembling the steps between Stephen Jay Gould's "punctuated equilibria" (Gould 1987).[48]

3. The "rule of double conditioning" means that "no 'local center,' no 'pattern of transformation' could function if, through a series of sequences, it did not eventually enter into an over-all strategy. Inversely, no strategy could achieve comprehensive effects if it did not gain support from precise and tenuous relations, serving not as its point of application or final outcome, but as its prop and anchor point." In equivalence to Haken's "principle of circular causality" the macroscopic patterns of neural mass action feed on the totality of neurons, "local centers," and neural circuits within them. In turn they reinforce the whole by imposing order onto ("enslaving") the parts. This macroscopic whole enters as a part into yet larger interactions by the global systems of brains.[49]

4. The "rule of the tactical polyvalence of discourses" addresses the process by which "power and knowledge are joined together. And for this very reason, we must conceive discourse as a series of discontinuous segments whose tactical function is neither uniform nor stable." By analogy, Neuroactivity evolves along complex trajectories, with discontinuities that mark the transitions among transiently stable states. We seek the markers by which to define times at which Neuroactivity is divided into stable segments by endogenous state transitions.

These rules neither predict nor explain, but they reflect an attempt to grasp in words what we encounter as we move conceptually from the local neural network and its clearly defined properties out to the limits of its utility, multiply the network to infinity, and then awaken into a new local network, in which the infinities of components are collapsed into the emergent elements at the next higher hierarchical level. This transcendence is among the most difficult passages to negotiate in science, because it goes across the boundaries that separate levels of understanding, and it requires a leap of intuition that cannot be reduced to formal logic or causality (Wimsatt 1976).[50] The passage is a separatrix, watershed, or continental divide, confining reductionists and logical positivists to the barnyards of concrete detail, and preventing them from conceiving the existence of the palace of global process.

48. Stephen J. Gould, *Time's Arrow, Time's Cycle: Myth and Metaphor in the Discovery of Geological Time* (Cambridge, Mass.: Harvard University Press, 1987).

49. Haken, *Synergetics* (above, n. 22).

50. W. C. Wimsatt, "Reductionism, Levels of Organization, and the Mind-Body Problem," in *Consciousness and the Brain: A Scientific and Philo-Sophical Inquiry,* ed. G. G. Globus, G. Maxwell, and I. Savodnik (New York: Plenum, 1976).

The Limits of the Self: A Case of the Essentialized or Determined Subject?

Might not our theories collide over two issues concerning the subject? Does our unity and wholeness reinscribe the modernist, essential subject—anathema to the postmodern project? Does Foucault's and Butler's constructivism imply determinism—anathema to neurodynamism? Actually, these differences are perspectival—ones of emphasis—and the perspectives themselves are heavily influenced by the discourses that each of the models is attempting to resist.

We whose audience is often the scientific community seek to stress our model's nondeterministic stance. Thus we emphasize the intentional nature of an organism's thrust into its surroundings. Yet, an organism is not autonomous; rather, it assimilates ontogenetically with the world in the manner described above. The example of sensation/perception in olfaction demonstrates how the bio-epistemologically unique subject shifts over time in intra-action with the world. Thus our biological theory is analogous to Foucault's philosophical theory that a subject is uniquely constructed in and by environmental discourses. Further, our theory incorporates Butler's emphasis upon a subject's continual change over time. Our work speaks eloquently to the charge that models such as Foucault's and Butler's cannot adequately account for materiality. Our model demonstrates that the body/brain is fully constructed in and through the world, importantly via the material changes of learning.

Foucault's and Butler's projects attempt to counter humanist conceptions of the individual autonomous subject; thus, their work emphasizes the impingement of the surroundings on the subject. They conceive of subjectivation as a production of environmental discourses, yet the very fact that they continue to use the term "subject" makes clear that they do not imagine a completely porous subject and that they continue to distinguish between self and surroundings. Moreover, the heterogeneity of power discourses in subjectivation belies determinism. The Butlerian conception of rearticulation discussed above offers an even more specifically antideterminist model. This constant reforming of subjects within conflicting discourses that interact and intersect enables change within subjects as well as between subjects. The possibility for alteration is opened by the unpredictability of the outcome.

Intentionality/Resistance-Agency and Chaos

Determinism versus nondeterminism is not simply a matter of unpredictability. Determinists assert that the future has already been fixed, although we cannot always predict it because our computers are too slow and our brains too dull. The alternative view that the future is not fixed requires us to challenge the nature of causality. Butler explicitly posits a noncausal relationship between input and output, which is analogous to our emphasis on a nondeterministic relationship between formative events.[51] We agree with Butler that it is impossible to know either the totality of the discourses forming a subject, or how much of a rearticulation of the subject will occur at any given time.[52] We agree with Foucault that large alterations in epistemes and thus in cultural understandings and cultural perceptions can occur suddenly, even with only small alterations in input discourse.[53]

Our conception of intentionality is explicitly grounded in a nondeterministic model of chaos. As outlined in the above examples, chaotic shifts in neural activity (state transitions) occur in relation to the organism's interaction with its surroundings. The neural populations in each of the brain's three major areas communicate with each other, forming chaotic patterns of oscillation that are governed by strange attractors. This is the neurobiological basis for intentionality.

Foucault's notion of resistance is analogous to our intentionality in that resistance is enabled within the web of varied and often conflicting discourses that surge through and around the subject. Foucault avoids locating resistance explicitly within individual subjects, largely because his project primarily seeks to unseat the autonomous humanist conception of man. Yet, Foucault's interest is primarily in subjects, and these resistances must logically be imagined as embodied in individuals while simultaneously being enabled by a convergence of power discourses. Furthermore, although his work is sometimes criticized as being deterministic, his model of subjects as always already embedded within unpredictable, shifting discourses leaves no room for the causal logic that a deterministic model necessitates. Indeed, his notion of resistance is similar to our intentionality and its corresponding state transitions in that each is always already embedded within the fabric of the environment, and yet the unpredictability of the alterations that they appear to catalyze make them significant to us.

Although the term "agency" usually bears humanist undertones and implies causal relationships, when considered in the explicitly

51. Butler, *Psychic Life* (above, n. 43); Freeman, "Consciousness" (above, n. 24); idem, *How Brains* (above, n. 18); idem, *Societies of Brains* (above, n. 34).

52. Judith Butler: *Bodies That Matter: On the Discursive Limits of "Sex"* (New York: Routledge, 1993); *Excitable Speech: A Politics of the Performative* (New York: Routledge, 1997); *Psychic Life* (above, n. 43).

53. Foucault, *The Order of Things* (above, n. 39).

Butlerian sense, agency is also analogous to our intentionality. Butler does not explicitly distinguish between the agency of the self and the self's personal sense of agency. Our model, in contrast, makes explicit that intentionality is the driver of action into the world, while the subjective sense of having initiated an action is an illusion. Such a distinction could be fruitful for Butler's attempt to unseat traditional notions of agency.[54] As does our project, however, her work calls the determinacy of agency into question, implicating instead unpredictable shifts in the subject over time and in relation to discourses (this although the subject's experience of agency might remain causal and personal). Similarly, our model explicitly describes causality as an anthropocentric tool, which arises by virtue of the experience of acting ("cause") and of sensing ("effect"), and which humans use to give meaning and order to their world. The imputation of causality in causal models parallels the imputation of souls in animism. Each paradigm focuses inward, then projects outward to model an explanation by means of which the sun is moved across the sky, the winds are made to blow, and the aims of mankind are frustrated by fate's designs. In our view, causality is a quale that we assign to webs of objects and events as part of our intra-action, our assimilation, with them.[55] Butler's agency and our intentionality rely on the indeterminate creativity of chaos.

Our conception of chaos is part of a larger dialogue involving two dominant understandings of chaos: the "order in chaos" model, and the "order from chaos" model.[56] N. Katherine Hayles points out that

54. Butler writes: "As much as a perspective on the subject requires an evacuation of the first person, a suspension of the 'I' in the interests of an analysis of subject formation, so a reassumption of that first-person perspective is compelled by the question of agency. The analysis of subjection is always double, tracing the conditions of subject formation and tracing the turn against those conditions for the subject—and its perspective—to emerge" (*Psychic Life* [above, n. 43], p. 29). Incorporating a notion of intentionality/agency that does not require an "I" would enable a more radical notion of a "subject after humanism."

55. We can by now see that qualia are intrinsically part of our intra-action with the surround. Here, a quale is the feeling of necessity, inevitability, and certainty in a connection that demands remedial, judicial, or preemptive action. That feeling is notorious for its fallibility. Oliver Cromwell railed against it in his letter to the General Assembly of the Church of Scotland (August 3, 1650): "I beseech ye, in the bowels of Christ, consider the possibility that ye might be mistaken" (*Bartlett's Familiar Quotations*, 15th ed. [Boston: Little Brown, 1980], p. 272). Individuals derive that feeling from their awareness of their actions and the sensory correlates of those actions as the basis for all knowing. The recognition of this power-knowledge duo in others is the basis for assignment of responsibility and blame in the operation of societies: see Freeman, "Consciousness" (above, n. 24).

56. See Weingart and Maasen, "Order of Meaning" (above, n. 5). We refer to the well-

the "order in chaos" adherents are primarily members of the scientific community.[57] These researchers see chaos as a way to model the surroundings more accurately, albeit with only limited predictability, by learning more about the deterministic order that already exists hidden in chaos.

The "order from chaos" model has more adherents in the nonscientific community, with notable exceptions such as Ilya Prigogine. This understanding emphasizes the creative nature of chaos, seeing it as a way to explain the full potential of the human condition.[58] Butler's later work and her reading of Foucault's *History of Sexuality* and "The Subject and Power" address the unpredictable nature of creative change most explicitly on the level of the individual subject.[59] Foucault's work, which imagines the possibility of large shifts in cultural epistemes, maps most clearly onto the "order from chaos" model at the level of a population. Most notable is that each of these models relies on the concepts of unpredictability and noncausality to garner a sense of the subject as nondetermined. An appeal to nondeterministic chaos thus underlies Prigogine's human creativity, Butler's rearticulation of the subject, Foucault's epistemes, and our intentionality.

Acknowledgments

We would like to thank Greg Keaton, Christopher Nagel, and our insightful referees for their helpful comments.

known property of nonlinear dynamic systems, for which output is not proportional to input. Large inputs can have no effect; small inputs can have enormous effect. Moreover, self-determined systems may be inaccessible to causal analysis. The question, for example, of whether Foucault was influenced by Ray Bradbury's 1966 science fiction short story "The Sound of Thunder," or intrigued by the popular furor surrounding Lorenz's "Butterfly Effect" (James Gleick, *Chaos: Making a New Science* [New York: Viking Press, 1987]), may not be answerable.

57. Hayles, *Chaos Bound* (above, n. 3).

58. It is interesting that such nondeterministic ways of understanding chaos are commonly thought to challenge the structures of the conventional scientific community, where funding and prestige may appear to depend on finding causal models as well as replicable results and risk factors. Truly revolutionary scientific advances, however, have often originated from acausal dynamic systems that model natural phenomena. Isaac Newton's groundbreaking gravitational model in differential equations, for instance, defies causality by running equally well forward or backward with time: see Walter J. Freeman, "Three Centuries of Category Errors in Studies of the Neural Basis of Consciousness and Intentionality," *Neural Networks* 10 (1997): 1175–1183.

59. Judith Butler: *Excitable Speech* (above, n. 52); *Psychic Life* (above, n. 43); "The Subject after Humanism" (work presented at "The Subject after Humanism" Graduate Seminar, U.C. Berkeley, 1999).