Foundations and the Ontological Quest:
Prospects for the New Millennium
The ontological implications of scientific inquiry on the foundations of cognitive sciences

Rome, Italy 7-10 January 2002

Brain and body: human acquisition of knowledge and wisdom through intentional action and perception of its consequences

Walter J Freeman

Department of Molecular & Cell Biology
University of California, Berkeley CA 94720-3200
tel 1-510-642-4220 fax 1-510-643-6791
wfreeman@socrates.berkeley.edu
http://sulcus.berkeley.edu

09 January 2002 4,596 words 11 pages

Outline

1. Introduction.

2. Epistemology through ontogenesis of the brain and body
   - Passive - reflex arc
   - Active - action-perception cycle
   - Thomist - intent-action-perception-assimilation

3. The neural basis for construction of individual experience.
   - Chaotic neurodynamics through neuronal interactions
     - Creation through abstraction and generalization
     - Assimilation through intentionality

4. The neural basis for construction of knowledge through culture.
   - Socialization through bonding
     - Isolation - autistic growth of individuals through Hebbian learning
     - Affiliation - formation of trust through joint action mediated by brain chemistry

5. Conclusions

Humans are finite, world is infinite
Social experience and trust lead to knowledge
Laws of science - tools, not truths, for example, causality
Emergence of wisdom

1. Introduction.

Today we address the cognitive sciences. These are broadly concerned with describing the processes and deriving the rules by which information from the world is gathered through the senses, processed in the brain, integrated, stored, retrieved, and deployed through muscular actions. There are many research pathways. Psychologists investigate the stages by which infants and children develop competence in dealing with their evolving worlds. Neurobiologists use novel imaging techniques to measure brain activity patterns relating to behavior. Neurologists observe and treat disorders of thinking and behavior in patients with brain damage, disease, ord abnormal development like autism and Tourette's. Neurophilosophers sift through systems of thought that have been distilled from millennia of human experience. Engineers and mathematicians design computer-based dynamic devices that simulate thinking, as we experience it through logic and phenomenology. Computer scientists devise models of logic and language. Oure talks in this session on the foundations of the cognitive sciences address these avenues of investigation. It is our task to distill some useful insights and perceptual constancies from our experimental investigations into human, animal and machine subjects. We intend these insights to be useful to philosophers and theologians, who seek to understand the philosophical and social consequences of these vigorously growing sciences.

We are mainly concerned with relations between cognition and behavior. We emphasize those aspects as "embodied cognition", in which we view the body as the principal tool of the brain for cognitive development and learning. We also use the term "situated cognition", to emphasize that structures in the environment determine, and are determined by, the actions of individuals seeking knowledge. It is a truism for most experimental scientists that knowledge of the material world comes through the senses. This view stands in opposition to alternative views that knowledge like language is implanted in the genome by evolution and is revealed to the individual in the course of ontogenesis, or that knowledge is received through spiritual intervention that is experienced by the individual as ontological inspiration or revelation. I state this truism at the outset to clarify my premise, that all knowledge is earned by individuals acting into the world and enjoying or suffering the consequences. The goal of *neuro*cognitive scientists like myself is to describe, in terms of brain dynamics, how actions are conceived, planned, and executed in the brain.

2. Now I will speak on epistemology by ontogenesis of the brain and body

Since the ancient Greeks, scientists have held two classical views about how our brains perceive their environments. Scientists in the tradition of Plato regard perception as passive. The classical metaphor is Plato's cave. Light coming from outside casts shadows on the walls and enters the eyes bearing indistinct and incomplete forms. These forms are refined and interpreted in the brain by reason, which matches them to ideal forms. Then actions are selected by ethical judgment using the moral faculty. In modern terms this view is described as information processing by the brain using hierarchies of reflex arcs and neural networks. Action begins with stimuli that drive the senses by patterns of energy, such as textures of light and dark, or of smoothness and roughness. These patterns carry the forms of objects. The sense organs encode the forms as information. The information is carried from the sense organs by action potentials through relays into the sensory cortices. There the information is combined into representations of stimuli that are stored in the frontal lobes. Later the representations are retrieved and compared with new information. Comparisons serve to classify fresh stimuli and to choose appropriate emotions and actions. Choices are governed by game theory. Actions and emotions are selected from mental models that are stored in the amygdala and basal ganglia. They are initiated by motor commands issued through the brain stem and spinal cord that move the body in response to stimuli.

This Platonic view is the basis for most widely accepted models of brain function, including artificial intelligence and neural networks. These models require that the brain maintain a store of idealized representations of objects, by which it can recognize them from incomplete glimpses that are corrupted by noise. This approach has given us some complex, sophisticated computer algorithms for pattern recognition by supervised learning, but it is widely acknowledged that their performance is inferior to that of the brain.

The alternative classical view held by Aristotelians is that perception is active. Movement of the body into the world by probing, cutting and manipulating is needed to determine the shapes, textures and weights of objects. Behavior is proactive, not reactive. This model is used in pragmatism, existentialism, Piagetian psychology, Gestaltism, ecological psychology, and now robotics and embodied cognition. In these modern views, information is embedded in objects that the brain seeks. A search begins when the brain creates a goal and needs information to achieve it. The brain directs its sense organs to find the required information in the world, using its cognitive map in the temporal lobe to direct the search. At the same time the brain prepares its sensory circuits by tuning them with copies of its motor commands called 'corollary discharges'. These messages focus the sensitivity of the sensory cortices onto the desired input. The information in the

forms of objects is detected by the senses, which send it to the sensory cortices. There it is extracted by resonances in the neural circuits that are tuned to what is being sought. The searching actions and the prior tuning constitute foresight and attention, which determine the entry of only the desired information, not merely whatever forms of irrelevant objects happen to enter the senses. A salient property of the resonances is the selection of information about the *uses* of objects, which J. J. Gibson called "affordances". The brain uses the extracted information to construct mental models that represent the objects. However, the brain is prone to error, because we see what we expect to see, or what we want to see. Expectations often fail to conform to reality. A problem for both classical views is to understand how the brain determines the truth of its representations. Both views postulate that the brain contains truth tables by which to judge veridicality. Biologists find no evidence for truth tables in brains, so the problem remains unsolved.

A third view differs from both of these classical views. It was pioneered by St. Thomas Aquinas in his program to make Aristotelian doctrine consistent with Christianity. The basic Thomist premise is the unity and inviolability of the self that is inherent in the brain and body. This unity does not allow forms or information to enter the self. Indeed, the impact of the world onto the senses does give rise to states of activity he called 'phantasms', but they are ephemeral and unique to each impact. They cannot be known. The function of the brain is to exercise the faculty of the imagination, which is not present in Aristotelian systems. It generalizes and abstracts over multiple phantasms, and thereby it *creates new* information. In the term used by both Thomas Aquinas and Jean Piaget, the new information *assimilates* the body and brain to the world. The word "assimilation" comes from the Latin "adaequatio", that is, "toward equivalence". It is not an adaptation by passive information processing, and it is not an accumulation of representations by resonances. For example, when we grasp a cup in order to drink, our brain doesn't make a representation. It shapes our hand to assimilate to the cup. It shapes the self for optimal interaction with a desired aspect of the world. The goal of an action is a state of competence that Maurice Merleau-Ponty called "maximum grip".

Assimilation is the beginning for all knowledge. Thrusting the body into the world makes visible the Thomist process of intentionality. Our word "intention" has come from the Latin "intendere", that is, "stretching forth". The thrust initiates the action-perception cycle, which is followed by changes in the self as it learns about the world, and ultimately about God, by assimilation of the self to the world. There is no transfer of information across the senses into the brain. Instead the brain uses chaotic dynamics to make its own information, because chaos can create as well as destroy information. It creates information by constructing a landscape of chaotic attractors, each with a basin like craters on the moon. Each attractor is a class to which a singular stimulus belongs. It is a generalization that includes the meaning of the class. A stimulus puts the brain state into the basin of

an attractor, to which it converges like a ball rolling to the bottom of a crater. Convergence deletes the extraneous detail of the singular instance, which is abstraction. For example, when we are thirsty, we see the cup and not its details. The attractor is a hypothesis that is tested by an act of observation and perception. The responses to expected stimuli exist before they arrive. With each breath and flick of our eyes, our brains create new landscapes with the imagination.

In this respect cognition is like digestion. The digestive system protects the integrity of the immunological self by breaking all forms of foodstuffs into elementary particles. The gut absorbs the particles, and the liver builds them into new complex macromolecules, each bearing the immunological signature of the individual. Similarly, events and objects in the world are reduced to sheets of action potentials in the receptor surfaces of the nose, skin and retina, like pinpoints of light in Sir Charles Sherrington's famous metaphor of the brain as an "enchanted loom". These are the "raw sense data" of analytic philosophers and the phantasms of Thomists. The action potentials are transmitted to the sensory cortices, where new forms are created by the chaotic dynamics of neuron populations. The necessity for this manner of function in both cognitive and digestive systems is the same. The world is infinitely complex, and the self can only know and use the information that it makes within itself. This is why conventional information processing fails, why neural networks cannot solve the binding problem or the figure-ground problem, why linguists cannot solve the problem of machine translation, why philosophers cannot explain the intentional relation of representations to objects, and why the artificial intelligentsia cannot surmount the limitations of expert systems. The unbounded complexity of the world defeats the classical Platonic and Arisotelian approaches.

3. Now I will describe the neural basis for the construction of experience.

The Thomist concept of intentionality offers a way to solve these intractable problems, because they stem largely from the attempt by Descartes to make mathematics the *foundation* of the natural sciences instead of its principal *tool* for quantitative analysis. Thomist philosophy in the 13th Century provided the basis for the growth of medieval science, medicine, law, industry, and navigation. It led to the Renaissance and to worldwide expansion of Western culture, but in the 17th Century it was replaced by Cartesian positivism, giving rise to 20th Century science. Since the current impasse is largely due to Cartesian dogma, Thomist doctrine, which was Descartes' target of opportunity, offers a well documented launch pad for a fresh start. In particular, the concept of intentionality offers a firm base for interpreting recent neurobiological data, that can explain how and why all knowledge is constructed in the brain and does not come from outside.

The evidence on which I base this assertion comes from experiments on animals that have been trained to respond to conditioned stimuli. I and others record the electrical potentials elicited by the stimuli as they course through the brain to the sensory cortices and beyond. The essential finding is that a sensory stimulus induces the cortex to create a spatial pattern. This happens alike in the visual, auditory, somatic and olfactory systems. The action potentials that are directly evoked by a stimulus are like swarms of water molecules in steam. Their impact induces the cortex to stabilize its activity, much as electrical forces induce water vapor to condense into a rain drop. The condensate sets up a shimmering pattern of activity in the cortex, which holds for a tenth of a second. Then it dissolves and a new pattern condenses. Each pattern is like a frame in a motion picture. Its appearance is unintelligible to the unaided eye, because it is written in the language of the brain, which is its electrical activity. We read it with electrodes to record action potentials and the electroencephalogram. The patterns generated by cortex are not representations of stimuli. They are neural discharges that give the meanings of stimuli for individuals. They depend on experiences that have been embedded in the synapses in cortical networks, which are different for everyone. The sensory cortices broadcast these spatial patterns, while the raw sense data, the phantasms, having done their work, are removed. The broadcast patterns overlap and combine, particularly in the temporal lobe. They form multisensory percepts known as Gestalts, which are integrated into recent memory and located in environmental space by the cognitive map in the hippocampus. At this stage they are ready for assimilation.

The completion of the intent-action-perception cycle by assimilation is by incorporation of the new learning into the life history of the individual. Here is the stage where phenomena are experienced and consciousness first appears in the cycle, long after the raw sense data, the phantasms, the flashing pinpoints of light, are gone. To be useful, each new experience must be integrated into the personal life-history, by which the results of actions are judged, new goals are created, and new actions are planned. In this view consciousness comes only *after* an action has been initiated, *not before*. Each of us perceives our actions as causes, and the sensory consequences as effects. No matter how brief the episodes, consciousness is essential for long term construction of chains of memories of cause and effect. Dreaming knits them into the whole of intentional structure. Our self-awareness through the intent-action-perception-assimilation cycle is the basis for our concept of causation. Studies by Piaget showed that this association of cause and effect is established in the somatomotor phase of development, before we learn to speak, when, as infants, we learn to control our bodies. How and why the experience of awareness comes to us are matters for speculation, but its phenomenology clearly shows the powers and limitations of this remarkable process. The temporal range of consciousness is enormous, but its momentary content is sparse. Each of our actions is influenced by our entire life history, but we are conscious of only minutiae in any brief

moment of thought. There is compelling clinical and physiological evidence that the temporal lobe is essential for constructing the life history. This is why we associate memory with the temporal lobe, even though we know that memories are not stored there.

4. Next I will address the neural basis for the construction of knowledge through culture.

Learning leads to assimilation, but assimilation by itself does not suffice for knowledge, because knowledge is intrinsically social. It is embedded in the cultures in and by which groups of humans live. Here is a profound question for neuroscientists and philosophers. Given that assimilation is by chaotic constructions within individuals that are unique in form and content to each individual, how can there be shared assimilation? The world is infinitely complex, and it offers a different face to each individual. No one can fully grasp any part in its fullness, owing to the finite scope of our skills in comprehension. This is the reason we live our lives by continually posing hypotheses and asking questions, that by their nature already contain the answers we get, and nothing more. The inherent tendency of the individual in this growth through learning is to become specialized and fade progressively from humanity, ever deeper into an arcane discipline that can be shared with fewer and fewer aspirants to like understanding. Such is the loneliness of isolated graduate students, which is comparable to the anomie of rootless urban drones, and the angst of intellectual dilletantes.

Assimilation through learning does not explain the biological mechanisms that bond individuals through socialization. Reinforcement learning supports the growth of a unified, self-organized, intentional structure, which is progressively elaborated, differentiated, and asocial. Unchecked it leads to isolation, lack of empathy, and inability to act in concert. Examples of extreme failures of socialization may include some autistic children and psychopaths who may have astonishing cognitive skills but are stunted emotionally. The neural mechanisms of learning with their tendency to isolate an individual must be countered by opposing mechanisms that mesh an intentional structure with others. The brain overcomes isolation by inducing chaos that dissolves its intentional structure and enables the emergence of new habits, beliefs and values through cooerative actions with others. In essence, the brain regresses to an earlier stage of development and makes a fresh start, this time with kindred souls.

There is abundant behavioral evidence for the existence and operation of such mechanisms of chaotic dynamics. The evidence is found in the widespread application of social techniques for behavioral modification in religious and political conversions, indoctrination of recruits into military troops and teenage gangs, and the group bonding that occurs in fraternities, sororities, and large corporations. These techniques do not change individuals through forgetting or loss of memory.

They restructure the intentionality of individuals. They induce deep, often dramatic, rarely catastrophic, changes in values and points of view that typically are life-long. They provide additional evidence, if any is needed, that brains are dynamical systems and not logical devices. Coercive uses of the techniques are widely known as "brain washing" and "re-education". Those uses unfortunately obscure the ubiquity and necessity of the techniques in normal socialization.

The biological aspects of the techniques for inducing dissolution are also well known. Individuals separate themselves or are isolated from their normal social surroundings and support networks. They engage in or are subjected to severe physical exercise as in dancing, sports, and military exercises, lack of sleep, chemical stresses to their brains through drugs and fasting, and powerful emotional states of love, hate, fear or anger. At some threshold the customary structure of the individual begin to crumble, and a collapse occurs that Ivan Pavlov described as 'transmarginal inhibition'. This is a stage of physiological arousal beyond which further excitation leads to paradoxical depression. There is regression to successively earlier levels of assimilation as the structure of intentionality dissolves, particularly with resurfacing of old patterns of relations to parental care. There is a loss of normal constraints and, in extreme instances, of language, locomotion, posture and even consciousness as the individual collapses. Recovery from collapse is followed by a state of extreme suggestibility, in which the skills of language and the competencies of daily living are regained, yet new values and habits can be established. This is done in social settings of loving care by attendants, who induce by example and exhortation the cooperative behaviors that lead to shared beliefs and, above all, to *trust* in new companions and the social organization they embody and provide.

Little is known about the neurochemistry of the changes that are induced in brains by chaotic dissolution. The antecedents of socialization are found in the processes by which bonding occurs in mammalian reproduction. The key chemical is a neuromodulator named oxytocin. This neuropeptide has been known for many years to induce parturition and lactation. More recently oxytocin is known to be released by the brain into itself during sexual intercourse, particularly during orgasm in both men and women. It is implicated in pair bonding not only of parent to child but also of parents to each other. The neurochemical actions of oxytocin in the brain are widespread, extremely complex, and difficult to study, so that much remains to be explored, but present knowledge shows it is capable of inducing the dissolution that enables new learning. A simple example is the release of oxytocin flooding the brain of a sheep during delivery of her second and later litters. Thereafter the dam refuses to nurse her earlier litters, having expunged the olfactory imprint required for maternal recognition. This is a primitive but well documented instance of dissolution that serves also to explain its biological utility.

Affiliation is realized by cooperative action with new associates, as in young parents who are learning to care for the next generation. Cooperation is the bedrock of social bonding for the same reason that the brain operates by creating and testing hypotheses as its method of information processing. Each individual in a social group is infinitely complex and can never be known completely by any other. Incomplete knowledge is compensated by trust, which transcends language, and supports unquestioned life-long allegiances. The social technology of bonding has been explored by anthropologists in studies of tribal rites of passage, ordeals, and ceremonies. They are accompanied by use of music, drumming, dance, and other forms of predictable repetitive actions, and by symbols such as flags, icons, totems, and, in modern times, corporate logos, military insignias, and the colored armbands of teenage gangs. As in the illustrations I show from Pierre Verger, the techniques commonly embody an enactment of death and resurrection, the birth of a new person.

5. Here are my conclusions.

The human brain is finite, whereas the world is infinite in its complexity and variety. We learn what we need and what we can by assimilation, which is more than storing information and adaptation by acquiescence. It is active intrusion into the parts of the world that are accessible to us, followed by the shaping of brain,body and world to meet our expectations, our projections, desires and dreams. Our cumulative experience, when shared with others of our kind through joint actions, supports the growth of knowledge. In the field of science, which is a vast transnational social enterprise, knowledge takes the form of *laws*. These laws are not eternal truths. They are tools by which we predict, plan, act and test hypotheses. An example is the law of causality by which we build chains of cause and effect through time, that are modeled on our perceptions of our own intentional actions. Causation is an essential social tool in courts of law for assigning responsibility and blame. This same tool is commonly used in science and technology for constructing linear causal chains, in search of convincing evidence, often referred to as "the smoking gun", which gives a feeling of necessary connection. But truth is not based on strength of belief, and if, ultimately, causation is nothing more than the feeling of necessity, then we should rely more on predictors and risk factors, and less on supposed agencies to determine our courses of action. A recent example was the claim by cigarette makers that there was no proof of a causal connection between smoking and lung cancer. That claim impeded efforts of public health officials to educate the public on the dangers of smoking.

It is vitally important that modern societies understand the brain functions of dissolution and affiliation. The natural breeding ground for terrorists is provided by the conditions in which young men and women are alienated, have no allegiance to any society, and see only the chaos of unbridled individualism around them. They are easy targets for indoctrination by fanatics, who can re-make them into merciless killers. Here we are at a frontier of brain dynamics. Neurobiologists do not have the data to model the dynamics. Sociologists do not understand the biology. Philosophers and judges look to the scientists for guidance. We must work together to explore this unknown territory and enable our societies to find levels of socialization, that are optimal between the extremes of anarchy and regimentation.

I conclude with remarks on wisdom. As brains age, they becomes rigid. Habits are fixed, points of view are frozen, and values become old-fashioned, as the world inexorably changes, and as new generations take over.

> "Yet, if aging brains get it right, rigidity is tempered by tolerance and detachment. With advancing years and the accumulation of experience, at some point the brain reaches a threshold, whereby it undergoes a state transition, such that on passage there is a remarkable coming together of all that is past, an awareness of global interconnectedness among the recollections over the years. This is the state of wisdom. It cannot be directly sought or striven for, but it is recognized when it comes, and it brings the serenity and graciousness of knowing how small the sense of self is, how transient are its aims and impacts, and how broad is the range of interconnection with other selves by influences too small to be singled out and labeled, yet undeniably acting within, in the way that a single neuron in cortex "knows" what is to be done from the field of activity within which it is embedded, without needing to know "why" or "what the big picture is". It is enough for a neuron to perform as a neuron is designed to do, and for a man or a woman it is enough to know that one has met a challenge or passed a test without realizing that a test was in progress. Not everyone achieves this state of mind, and it is not communicated in words or by teaching, but it is there, and it has been written about, and when it arrives, one knows that the future has joined with the past to make a circle outside time. One needs nothing more, for this suffices, reaching the wholeness of mature human intentionality" (Freeman 1995).

References

Aquinas St. Thomas (1272/1952) The Summa Theologica. Translated by Fathers of the English Dominican Province. Revised by Daniel J Sullivan. Published by William Benton as Volume 19, Great Books Series. Chicago: Encyclopedia Britannica, Inc.

Freeman WJ (1995) Societies of Brains. A Study in the Neuroscience of Love and Hate. Mahwah NJ: Lawrence Erlbaum Associates.

Freeman WJ (2000) Come Pensa il Cervelo. Milano: Einaudi.

Merleau-Ponty M (1945/1962) Phenomenology of Perception. (C Smith, Trans.). New York: Humanities Press.

Piaget J (1930) The Child's Conception of Physical Causality. New York: Harcourt, Brace.

Sargant WW (1957) Battle for the Mind. Westport CT: Greenwood.

Sherrington CS (1940) Man on his Nature. Cambridge: Cambridge University Press.

Verger P (1954) Dieux d'Afrique. Paris: P Hartmann.