The Frontal Feedback Model of the Evolution of the Human Mind: Part 2, The Human Brain and the Frontal Feedback System

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The frontal feedback model argues that the sudden appearance of art and advancing technologies around 40,000 years ago in the hominid archaeological record was the end result of a recent fundamental change in the functional properties of the hominid brain, which occurred late in that brain's evolution. This change was marked by the switching of the driving mechanism behind the global, dynamic function of the brain from an "object-centered" bias, reflective of nonhuman primate and early hominid brains, to a "self-centered" bias, reflective of modern Homo sapiens and perhaps late Homo erectus brains. Such a change in the global–functional properties of the brain was provided for by the progressive enlargement of the primate frontal lobe throughout its evolution. In late-developing hominids, this progressive enlargement effectively succeeded in *reversing* the preferred direction of information flow in the highest association areas of the neocortex from a caudo–rostral bias to a rostro–caudal bias. It was this reversal specifically that provided for the ability of humans to use symbolic thought in the creative expression of art, language, and the development of advancing technologies. Part 2 discusses the specific changes in the brain that occurred as a result of the reversal and how those changes were and are manifested as human abilities and experience.

In Part 1 of this two-part paper, a model was outlined for the evolution of the pre-human brain from its early vertebrate beginnings through to the appearance of mammals, primates, and finally the presumed common ancestor of the great apes and humans. The evolution of that brain, in particular the

mammalian form, was marked by a developmental constraint that favored the elaboration of the sensory systems in lieu of the elaboration of the motor systems. This constraint insured that the preferred direction of information flow in that brain proceeded from the dorsally and caudally situated sensory systems toward the rostrally and ventrally situated motor systems. Such a constraint provided a general mechanism for the governance of dynamics in the brain, the perception–action cycle, a cycle driven by the appearance of object–entities (sensory stimuli) in posterior sensory cortices and the animal's responses to those object–entities. In short, the "cognitive" world of the pre-human mammalian brain was said to be best characterized as being "object-centered" insofar as the brain's dynamics was driven by, or centered upon, the presence of concrete object–entity representations.

Here, in Part 2, it will be argued that the major developmental constraint driving the evolution of the pre-human brain outlined above was broken in hominids.[1] The breaking of this constraint was provided for by the progressive development of the primate/hominid hand and the prefrontal motor cortex controlling that hand as the development of these anatomical features began to assume a selective advantage to life in the trees and later on to life on the savannah. At some point in the late development of this hand/brain apparatus in hominids, the ensuing disproportionate enlargement of the prefrontal motor cortices effectively succeeded in *reversing* the preferred direction of information flow in the cortex to a rostro–caudal bias (Noack, 1995a). Thus, the perception–action cycle that had served the pre-human form of the brain so successfully for so long had been turned upside-down, or more specifically, *turned inside-out*. It was replaced by a uniquely human "frontal feedback system," which, as its name suggests, was marked by a feeding back of activity from the once-recipient regions of the prefrontal motor cortices to the once-projecting posterior sensory systems (Noack, 1995a, 1995b, 2004, 2006a, 2006b, 2006c, 2007). As will be detailed in this paper, the effect of essentially reversing the dynamics of the perception–action cycle was profound in that it created a dynamic entity in the hominid brain known as the central character, or "self," and organized an entire virtual world around that central character for that character to exploit to its selective advantage. Thus, the cognitive world of the early human brain began to become "self-centered" insofar as its dynamics were driven by the presence of this self and, accordingly, the needs of this self in its exploitation of its created virtual world. From that point on, the fundamental developmental constraint on the evolution of the brain switched from favoring the development of the sensory systems over the motor systems to that of favoring the development of the motor systems over the sensory systems.

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[1]In this paper, the term "hominid" refers to modern-day humans and the line of hominoid primates now extinct, such as the australopithecine and early homo species, that branched off from the common ancestor of the great apes and humans, leading to the modern human species.

Evolution of the Mammalian Brain

Information Flow in the Neocortex

In order to argue that a rostro–caudal reversal in information flow did, indeed, take place in the hominid brain, it is first necessary to argue that the pre-human mammalian flow of information in the cortex was caudo–rostral. In order to do that, it is necessary to once again look at how neurons and cortical areas interact with each other dynamically at local and global scales. In general, larger cortical areas or systems of areas exert more control over global cortical dynamics than do smaller areas or systems, resulting in the larger regions controlling or driving the activity in smaller systems (Noack, 1995a). The reason for this is twofold. The first reason has to do with the fact that larger cortical regions tend to have more neurons and more interconnections between those neurons (neuropil, see Part 1 [Noack, 2006c]) than do smaller cortical regions. Each of the millions of axo-dendritic synapses that define these interconnections produces a small electrochemical current when stimulated by an incoming action potential that loops through the axon hillock, or trigger zone, of the neuron (Freeman, 1995, 2000). Since excitatory signals summate, the cooperative behavior of a large number of neurons and interconnections between those neurons tend to produce higher-amplitude carrier waves within their populations than do smaller areas (Bressler and Kelso, 2001). These larger populations with higher-amplitude carrier waves can then significantly affect the behavior in smaller populations with lower-amplitude carrier waves through the higher density of action-potential pulses that are emitted from the larger region.

To put it another way, the carrier waves reflect "wave packets" of information that are formed when synchronous activity in a given region of neocortex converges on a chaotic attractor representing, say, a given sensory stimulus (see Part 1 [Noack, 2006c] and Freeman [2003]). Since fully 60–70% of the neuronal interconnections in any given cytoarchitectonically defined cortical region originate from within that region (Young, 2000), the wave packet represents a powerful and integrated form of information currency that spreads out from its germinal cortical region to affect the other regions with which it is connected. These recipient regions form what is known as the projection region's "connection set" (Bressler, 2004) or "connectional fingerprint" (Passingham, Stephan, and Kotter, 2002), and a large projection region producing a powerful wave packet can significantly influence the activity or formation of wave packets in a smaller region through the high density of pulses emitted from that region (Freeman and Barrie, 1994).

The second reason a large cortical region tends to drive the activity in a smaller region has to do with the manner in which cortical regions are inter-

connected anatomically. One general principle of brain evolution holds that as various brain regions evolve, the ones that grow disproportionately large compared to the others tend to command more of the brain's connectional circuitry. This so-called "large equals well-connected" (Striedter, 2005) rule essentially holds for the neocortex as well as other brain areas, but holds more for the size of regional clusters, families, or systems (such as the visual system) of cortical areas rather than for the individual cytoarchitectonically defined region (Hilgetag, 2006). For example, the projections from any one given cortical region to another tend to account for less than 5% of the excitatory synapses in the recipient region regardless of the disparity in the sizes of those regions (Young, 2000). A cortical *system* compensates for this small, individual influential effect essentially by converging the outputs of its many individual areas onto any given recipient region/system in its connection set (Bressler, 2004). Through this combinatorial process, one cortical system with a large number of individual regions can provide as much as 40% of the excitatory synapses in a relatively smaller cortical region/system, thereby exerting a particularly influential effect in that recipient region/system (Bressler, 2004; Young, 2000).

Revisiting the Evolution of the Neocortex

Using the concepts presented above, then, some indication of the evolution of cortical function can be gleaned simply through looking at the comparative anatomy of mammalian brains. Upon such analysis, what becomes immediately clear is that the representation of sensory cortical regions in virtually all mammals greatly outstrips that of the representation of motor cortex (Kaas, 1989, 1995). In fact, the earliest pre-eutherian mammalian neocortices essentially had no motor cortex at all (Kaas, 2005), only what has been referred to as a "sensori-motor amalgam," a region of cortex where somatosensory and motor processes were combined (Striedter, 2005). A dedicated cortical motor strip, or M1, is not found until the appearance of eutherian (placental) mammals, roughly 100 million years after the primordial neocortex first appeared (Kaas, 2005). By the time eutherian mammals appeared, the sensory systems had already been significantly developed in the majority of those animals and have continued to remain more developed than the motor systems up to the present.

The point of the above discussion is to argue that the dynamical features of the mammalian perception–action cycle discussed in Part 1 were a constraint put on the evolution of mammalian brains right from the very genesis of that brain. It is apparent from looking at the evolution of the mammalian brain that the early, and most likely later, development of the cortical motor systems was largely shaped through the controlling or driving influence of the cortical sen-

sory systems. Such a constraint yielded the highly effective perception–action cycle form of dynamical regulation of cortical activity, which is the hallmark of mammalian brain function (Fuster, 1989, 2003; Noack, 1995a). Again, looking at the comparative anatomy of mammalian brains, it appears that diversity was achieved within this constraint mostly through competition for cortical representation by the sensory systems rather than by the motor systems (Krubitzer and Kahn, 2003). This competition was geared specifically toward deciding which sense modality had priority control in driving the dynamics of the perception–action cycle, which, in turn, was a developmental constraint linked to the specific ecological habitat of that species. For example, macaque monkeys have a disproportionately large visual system representation (Van Essen, 2004), which was helpful to living in an arboreal habitat, while ghost bats have a disproportionately large auditory system that aids in their processing of echolocation signals (Krubitzer and Kahn, 2003). As a whole, though, the totality of sensory–cortical representation in both these species greatly outweighs that of the representation of the motor systems, leaving intact in both the main driving mechanism of the perception–action cycle.

Evolution of the Primate Brain

The Rise of the Primates and the Development of Fine Motor Control

Living in an arboreal habitat places certain selective pressures on the development of an animal not found in those animals living on the plains. The visual detail in a forested habitat is enormously complex and requires a well-developed visual system in order for the animal to make distinctions between and among the abundance of individual leaves, branches, foods, predators, and mates the animal will encounter daily (Jerison, 1973; Sarnat and Netsky, 1981). It was this selective pressure that led to the enormous development of the primate visual system throughout its phylogeny. In addition to this selective pressure on the development of the visual system was the associated pressure to develop the motor capacities of the animal in order to negotiate that arboreal habitat. The stereoscopy and high-resolution distinguishing abilities of the visual sensory system are only useful to the animal if it can use that information, say, to brachiate through its environment, pick fruit, clear leaves, clean foods, and so forth (Gibson, 1990; Parker and Gibson, 1979). Therefore, as well as being distinguished by the development of their visual system, primates are also distinguished by the development of their forelimbs and hands along with the frontal motor systems of the brain that control those appendages. This focused pressure to develop the motor systems is unique to primates and is reflected in the comparative development of the primate prefrontal cortex relative to posterior sensory regions throughout primate phy-

logeny (Bush and Allman, 2004). For example, the prefrontal motor cortex of the plains-dwelling cat and dog represent only 3.5% and 7%, respectively, of the total amount of neocortex in these species, the rest belonging primarily to posterior sensory cortex (Changeux, 2004; Fuster, 1989; Goldberg, 2001). In primates, however, we see a clear trend toward the development of the motor systems relative to the sensory systems. For example, the prefrontal cortex of the lemur, an early primate, still represents only 8.5% of total cortex. However, in later-developing primates, this figure grows to 11.5% in the gibbon and macaque, and 16.9% in the chimpanzee (Changeux, 2004; Fuster, 1989; Goldberg, 2001). This figure increases even more dramatically in hominids and especially humans, as we will see below.

The Evolution of Bipedalism, the Hominid Hand, and the Prefrontal Cortex

The above discussion demonstrates that the story of the development of the human hand begins long before our ancestors started walking on two legs in order to free up the use of that hand; it actually starts when the first primates took to the trees (c. 60 mya). Therefore, when our early hominid ancestors *did* come down from the trees and started walking bipedally (c. 6 mya) [Calvin, 2004; Galik, Senut, Pickford, Gommery, Treil, Kuperavage, and Eckhardt, 2004], they already had a relatively well-developed hand–brain apparatus with which to manipulate objects on the savannah (Pinker, 1997). It was largely the freeing of that hand for use in the manipulation of objects (along with the height advantage of standing upright) that probably led to bipedalism's selective advantage and its persistence as a feature of hominid design (Calvin, 2004; Pinker, 1997). The persistence of the feature of bipedalism then led to the further development of the hand, including a fully opposable thumb and, correspondingly, the further expansion of the hominid prefrontal cortex as hominids started to grab, throw, and pound everything they could get their new hand on. Accordingly, in the human, we see the greatest development of prefrontal cortex to the extent that it comes to occupy almost a full third of the total amount of cerebral cortex (Changeux, 2004; Fuster, 1989; Goldberg, 2001).

Of key interest to the frontal feedback model in this reconstruction of hominid evolution is the micro-anatomical structural and functional changes that were occurring in the hominid brain during the on-going development of this hand–brain apparatus. At some point in that development, it is argued here that the expansion of the prefrontal cortex became so great that the feedforward signaling driving the coordination between the hand and the eye effectively stopped and began to turn back on itself in the highest association cortices. The lower-level sensori-motor networks were likely spared the effects of this reversal due to their phylogenetic age, which probably saved the brain

from a complete cataclysmic "short-circuiting." That is, lower-level sensori-motor networks were likely able to carry out basic survival duties (in the traditional perception–action cycle direction) while this new property of frontal feedback worked itself out in the higher association cortices (see below for a more detailed discussion). It was very possible, too, that it would not work out: frontal feedback appeared essentially out of nowhere, a design feature of cortical function with absolutely no precedent and accordingly with no apparent existing infrastructure to support it. Therefore, frontal feedback very easily could have had a detrimental effect and been negatively selected *out* of evolution. Remarkably, though, frontal feedback was able to utilize the existing structure to confer a selective advantage in hominids, and, as argued here, it is the development of this "frontal feedback system" that defines the story of hominid evolution and, thus, the evolution of the human mind.

Of course, before a proper discussion can begin on how the frontal feedback system works to achieve its effects, it is first necessary to make the argument that a fundamental reversal in the preferred direction of information flow did, indeed, occur in the hominid line. Noack (1995a) outlines three converging lines of evidence — anatomical, physiological, and cognitive/behavioral — that suggest the presence of a frontal feedback system in humans and its absence in nonhumans. That evidence will be restated here with some embellishment to reflect new developments and research in those fields.

Evidence for a Frontal Feedback System in the Human Brain

What is the Frontal Feedback System?

In order to argue that a fundamental reversal of information flow did, indeed, occur in the hominid brain and that it did, indeed, create a uniquely human frontal feedback system, it will be first useful to define exactly what the frontal feedback system is. The frontal feedback system is an integrated, functional unit within the neocortex of the human brain where the influence of action–scheme sequences active in prefrontal regions feeds back on and drives the activity in posterior sensory regions. The effect of this "top–down" prefrontal-feedback driving influence on the activity of these posterior sensory areas is much like that of the "bottom–up" feedforward driving influence of those same sensory areas by the sense organs in that each act to trigger chaotic attractors, or wave packets, in those posterior sensory regions. These wave packets are representative of a given object or other form of stimulus in the animal's environment. The difference between the top–down frontal feedback effect and the bottom–up sense-organ effect, however, is that the bottom–up effect tends to drive the formation of attractors in sensory regions that are reflective of actual objects in the animal's environment, objects that evolve

along a trajectory determined by physical laws. The top–down feedback effect, on the other hand, tends to drive the formation of fictitious, abstract sensory forms that evolve along a trajectory determined by the organization of action–schemes in prefrontal cortices, an organization that is hierarchical and sequential (Fuster, 1989; Greenfield, 1991). Thus, whereas the perception–action cycle can be defined as the caudo-rostral path that the effect of a sensory stimulus takes through the cortex as it is being converted into an associated action–scheme (see Part 1), the frontal feedback system can be defined as the rostro–caudal path that the effect of an action–scheme takes through the cortex as it is being converted into a "thought" (Noack, 1995a). This rostro–caudal path runs directly opposite the path of the perception–action cycle described in Part 1, that is, from the prefrontal cortex through to sensory-association areas and finally toward primary sensory areas anisotropically through the sensory processing streams.[2]

Another important distinction between the perception–action cycle and the frontal feedback system is that, while activity in the perception–action cycle moves in one direction only in order to achieve its desired effect, caudo–rostral, activity in the frontal feedback system *oscillates* between strong frontal feedback driving influence and weak frontal feedback driving influence in order to achieve its desired effects (Noack, 1995a). It is this oscillatory activity within the frontal feedback system that reflects the dynamic interplay between thought and perception, which defines the human experience. Specifically, strong frontal feedback driving influence toward primary sensory areas reflects the mind deep in thought insofar as the influence of frontal action–schemes completely occupy the processing fields of posterior sensory cortices. Weaker frontal feedback driving, on the other hand, reflects the mind perceiving a sensory stimulus in that the weaker driving allows sensory stimuli to occupy the cortical sensory systems through its influence pushing up from the bottom–up direction (Noack, 1995a). As described in Part 1 and in Noack (1995a), the feature of brain function that regulates these oscillations is simply the reward value of activity present in these posterior sensory cortices at any given moment. Thus, a rewarding thought will drive up the activity of the frontal feedback system, pushing the influence or boundary of that influence caudally more toward the primary sensory systems whereas a significant or rewarding sensory stimulus will have the opposite effect: it will push that boundary rostrally toward sensory-association areas or even as far rostrally as frontal motor areas (see below). It is this oscillatory effect in the frontal feedback system that allows the human to be snapped out of a deep thought by the

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[2]In this paper, the term "anisotropic" refers to the unique and differentiated physiological/behavioral effect that a flow of information has running in opposite directions through the same cortico–cortical pathway or series of such pathways.

presentation of a significant sensory stimulus such as a fast-moving object approaching him or her. Conversely, it is also this oscillatory effect that is responsible for a determined, rewarding thought to override the influence of such a significant sensory stimulus if the thought commands greater reward activity in those posterior sensory areas. It is this ability of the frontal feedback system to selectively override the influence of sensory stimuli that humans experience as the phenomenon of "mind over matter," a property unique to that species.

Anatomical Studies

Now that a general functional definition of the frontal feedback system has been outlined, it is possible to begin outlining its gross anatomical organization. Again, while the influence of frontal feedback can at times run anisotropically back through the entire sensory processing stream toward primary sensory areas, the feedback influence as a dynamic entity ordinarily oscillates between the poles of the primary sensory and sensory association areas. However, there are areas of the frontal feedback system that are relatively infrequently strongly driven by bottom–up sensory processes, and it is those areas that can be considered the "core" of the frontal feedback system. These areas constitute regions of the prefrontal cortex and the highest sensory association regions of the parietal, occipital, and temporal lobes (Noack, 1995a).[3] These areas are often referred to as the "silent," or "association," areas of the human neocortex insofar as their constitutive neurons do not respond robustly to the presentation of sensory stimuli. The reason for this silence, according to the frontal feedback model, is that they are busy creating their own internal sensory representations in the human.

It is interesting to note that, while these silent association areas (including prefrontal) represent only 25% of the total amount of neocortex in the macaque monkey, they represent over 50% of the total amount of neocortex in humans (Van Essen, 2004). This disparity is exactly the opposite of the case of visual–cortical representation in each species. That is, visual–cortical regions in the macaque account for over 50% of the total amount of neocortex whereas visual–cortical regions in the human account for only roughly 25% (Van Essen, 2004). According to the cortical information-flow argument put forth earlier in this paper, then, this 180-degree shift in the parcellation of visual and prefrontal/association cortex in macaque and human brains is suggestive evidence that there was a fundamental reversal in the preferred direction of information flow in the human brain. However, even with this

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[3]The core regions of the frontal feedback system can be largely identified with regions outlined in Golland, Bentin, Gelbard, Benjamini, Heller, Nir, Hasson, and Malach (2007) to belong to the "intrinsic" cortical system in humans (see below for more discussion).

glaring "tilt-of-the-scale" anatomical disparity, arguing for the existence of a frontal feedback system in humans from anatomical evidence alone is insufficient. Physiological evidence, of course, would be much more convincing. Indeed, such studies *do* support the presence of a frontal feedback system in humans and its absence in nonhuman primates.

Physiological Studies

The first question to ask in an attempt to interpret how physiological data relate to the frontal feedback system is this: What sort of activity would we expect to see in a perception–action-cycle type system versus a frontal feedback type system? According to the model, in the nonhuman perception–action cycle brain such as the macaque, we would expect to see a general transference of information, or information flow, through the cortex in a caudo–rostral direction with a high amount of "throughput" in that flow. The high amount of throughput would allow for the fast, efficient operation of the perception–action cycle and thus the ability of the monkey to respond quickly and reliably to sensory stimuli. In the human frontal feedback brain, on the other hand, we would not expect to see this same caudo–rostral driving throughput. In fact, what we would expect to see in the human is the bottom–up influence of sensory stimuli being confined to the earlier regions of the sensory processing stream and for that influence to oscillate back and forth between primary sensory areas and sensory-association areas (see above).

In 1995, when the frontal feedback model was first discussed (see Noack, 1995a), there was no reliable way to directly test the central reversal hypothesis of the model since techniques to measure the directional causality of information flow in the cortex had not yet been well developed. Therefore, indirect evidence was presented in that paper that suggested a reversal in information flow in the human brain using the throughput criteria discussed above. The studies cited analyzed the single-unit activity of neurons in the temporal–cortical sensory-association areas. These neurons are placed midway between primary sensory and primary motor areas in the sensorimotor processing stream, and the behavior of these neurons can be suggestive of the direction of information flow through that stream. Those studies found that temporal–cortical activity in the macaque exhibited a robust response to sensory (visual) stimuli (Fuster, 1989) whereas human temporal–cortical activity did not (Ojemann, Creutzfeldt, Lettich, and Haglund, 1988). Instead, human temporal–cortical activity was more related to hierarchical, sequential processes such as language production (Ojemann et al., 1988). The implication of this evidence was that, since these temporal–cortical areas responded to the bottom–up driving of sensory stimuli, the macaque cortex was showing a robust caudo–rostral throughput of information flow at this mid-way point

in the cortical processing stream whereas the human cortex was not. In fact, the evidence suggested that the flow of information in the human cortex was the reverse of the macaque. Additional evidence not discussed in that paper but available at the time was that single-unit activity even in the prefrontal cortex of the macaque responded robustly to visual stimuli, further reinforcing the nonhuman caudo–rostral throughput model (Fuster, 1989).

In the decade since the publication of the Noack (1995a) paper, several new techniques have been developed to analyze the manner in which information moves about the cortex. Some of these techniques rely on a statistical analysis of EEG activity or local field potentials as taken from intracranial electrodes (Brovelli, Ding, Ledberg, Chen, Nakamura, and Bressler, 2004; Chen, Bressler, and Ding, 2006), but most have come from revolutionary advances in neuroimaging (Bitan, Booth, Choy, Burman, Gitelman, and Mesulam, 2005; Friston, Harrison, and Penny, 2003; Penny, Stephan, Mechelli, and Friston, 2004). The wealth of data coming from these studies further supports and corroborates the foundational functional principles of the frontal feedback model outlined in the Noack (1995a) paper.

One pivotal study analyzed the response in prefrontal cortical areas in macaques and humans to a significant sensory (visual) stimulus (Denys, Vanduffel, Fize, Nelisen, Sawamura, Georgieva, Vogels, Van Essen, and Orban, 2004). What was found in the macaque, consistent with the Ojemann et al. (1988) and Fuster (1989) data, was a robust response to the visual stimulus in cortical areas running along the entire sensory processing stream. This robust response was even seen in the prefrontal cortex, where its level of activation was largely unattenuated, suggesting a high throughput of information flow through that caudo–rostral stream. In the human, on the other hand, the authors were surprised to note that similar activation of these areas was not found upon the presentation of a visual stimulus (Denys et al., 2004). In fact, not only was the prefrontal cortex relatively silent in response to the visual stimulus, but almost the entire temporal cortex was silent in response to the stimulus as well. The only activation that was seen was in a region of the early visual processing stream known as the lateral occipital complex, again consistent with the frontal feedback concepts outlined above. Additional neuroimaging evidence to corroborate the Ojemann et al. (1988) study shows that the prefrontal and temporal cortical areas that were silent in the Denys et al. (2004) study become active only during internal cognitive processes such as that seen in language production (Friederici, Ruschemeyer, Hahne, and Fiebach, 2003; Humphries, Love, Swinney, and Hickok, 2005; Vandenberghe, Nobre, and Price, 2002).

In addition to neuroimaging studies supporting the "throughput" functional aspect of the frontal feedback model are studies supporting the "oscillatory" functional aspect of the model. This oscillatory aspect is that, in the human

brain, the effect of prefrontal cortical driving influences will extend toward primary sensory areas during deep thought, imagination, or cognition, but will recede rostrally toward sensory-association regions during moments of sensory perception (Noack, 1995a). Indeed, this is exactly what was found in a series of studies designed to analyze differences in the flow of information in the human cortex during the perception of a visual stimulus and the mental visual imagery (a cognitive process) of the same stimulus. It has been demonstrated on many occasions that, in the absence of a particular visual stimulus, the focused mental imagery of that stimulus can create activity in early visual–cortical regions that is topographically similar to that created by viewing the actual stimulus (Kosslyn, 2005; Slotnick, Thompson, and Kosslyn, 2005). When looking deeper into this phenomenon, researchers have found that the production of the imagined stimulus is accompanied by a strong rostro–caudal driving of activity running from the prefrontal cortex through the posterior sensory-association areas and finally through the entire visual processing stream toward primary visual areas (Ishai, Ungerleider, and Haxby, 2000; Mechelli, Price, Friston, and Ishai, 2004; Mechelli, Price, Noppeney, and Friston, 2003). Consistent with the assertions made in the Noack (1995a) paper, these authors conclude that the cognitive/imaginary process is one characterized by top–down, rostro–caudal control. In contrast to the results from the imagery task, the visual perception task showed only robust activation in the early visual processing stream, leaving the prefrontal regions relatively silent (Ishai et al., 2000; Mechelli et al., 2003, 2004). Again, these results are consistent with the Noack (1995a) paper, with the authors of the study concluding that visual perception is a bottom–up process that runs from the primary sensory areas toward more rostral visual-association areas.

Although certainly not conclusive, the combined anatomical and physiological evidence presented above highly suggests that a fundamental reversal of information flow did, indeed, occur in the line of hominid primates that led to humans, and that it was this reversal specifically that provides for the unique features of the human mind. The precise manner in which that reversal and the frontal feedback system it created produces the human mind will be discussed in detail shortly. First, however, it will be helpful to outline briefly how the frontal feedback system develops ontogenetically in the human brain, which also will yield insight into how the frontal feedback system may have developed phylogenetically in the hominid line.

Developmental-Cognitive and Behavioral Studies

Although it is likely that a nascent perception–action cycle is operational in the vast majority of nonhuman mammals at birth, an operational frontal feedback system is certainly *not* present in the human brain at birth (Noack, 1995b,

2006b). In fact, it appears as if the early postnatal human brain functions much like that of its nonhuman primate ancestor by indeed operating on the perception–action cycle framework. The nascent frontal feedback system in humans does not come "online," so to speak, until the child's second year of life, and the cognitive development of the child from then on can be viewed as a process that corresponds to the progressive development of the frontal feedback system (Noack, 1995b, 2006b). This development is marked by the steady increase in the size of the prefrontal motor regions relative to posterior sensory regions postnatally through adolescence (Fuster, 2002; Giedd, Blumenthal, Jeffries, Castellanos, Liu, Zijdenbos, Paus, Evans, and Rapoport, 1999) and corresponds to the greater and greater influence of frontal feedback in the child's brain as that influence pushes toward primary sensory areas. This process of pushing the influence of frontal feedback further and further caudally in the cortex yields various dynamically distinct modes of operation in that cortex that can be identified loosely with Piaget's various stages of cognitive development (see Fuster, 2002; Gruber and Voneche, 1977; Piaget and Inhelder, 1969; see Parker and McKinney, 1999 for a more detailed description of these stages). Moreover, these stages can be seen to recapitulate the *phylogenetic* development of the hominid line from the common ancestor of humans and the great apes through to modern day Homo sapiens (Parker and McKinney, 1999).

Piaget's first stage, the "sensorimotor stage," corresponds to the first two years of the child's life and is identified by the series of sensorimotor coordinations the child develops to negotiate sensory stimuli. According to the frontal feedback model, this stage corresponds to a pre-human perception–action cycle mode of cortical operation insofar as the development of the cortex at this stage favors the posterior sensory areas over the frontal motor areas (Huttenlocher and Dabholkar, 1997). However, this bias in the development of the cortex begins to *reverse* between one and two years of age as the prefrontal regions of the child's brain undergo a rapid expansion relative to posterior areas (Huttenlocher, 1979; Huttenlocher and Dabholkar, 1997; Webb, Monk, and Nelson, 2001). It is at the end of this initial rapid development of the prefrontal cortex that we see Piaget's next stage of cognitive development appear, the "pre-operational stage." This stage is marked by the beginning of "semiotic," or symbolic, thought whereby the child begins to use objects and words to stand for something else. According to the frontal feedback model, the pre-operational stage reflects the preferred direction of information flow in the cortex turning around on itself and beginning to push caudally toward primary sensory areas. In this journey toward primary sensory areas, one of the first regions of the cortex to be affected by this frontal feedback is the posterior sensory-association areas that house the child's more abstract "category attractors" (see Part 1). In the nonhuman perception–action cycle, these category attractors represent general classes of sensory stimuli, which are acted

upon through their association with specific action–scheme sequences in pre-frontal cortices. In the pre-operational child, however, these category attractors begin to be "manipulated" as class-related symbolic entities through the influence of prefrontal action–schemes moving caudally.

In short, the symbol-processing abilities that distinguish the human mind so qualitatively from those of all other animals can easily be explained using the frontal feedback model: hierarchically organized, sequential action–schemes in prefrontal cortex manipulate the re-construction and re-creation of sensory representations in early visual cortex through the manipulation of generalized, class-related attractors in sensory-association cortex. One of the earliest manifestations of this symbol-manipulative property of the frontal feedback system in the child's development is a phenomenon known as "deferred imitation." Deferred imitation refers to the child's imitation of an event or imitation of the behavior of another individual at some point well after that event or behavior occurred (Gruber and Voneche, 1977; Piaget and Inhelder, 1969). One example would be a child pretending to turn an imaginary steering wheel well after a family car trip has ended. Presumably, this imitative behavior assists the child in somehow re-creating the memory of the family's trip in the car. According to the frontal feedback model, such imitative behavior is an early physical manifestation of the nascent effects of frontal–cortical action–schemes attempting to invade posterior sensory cortices in order to reactivate those areas in the retrieval of memories. The overt expression of the imitative behavior probably helps to boost the weak frontal feedback effect present at this early stage in the child's development. As the frontal feedback system develops, however, the requirement for these overt imitative behaviors vanishes as there is sufficient strength internally to drive posterior sensory regions (Noack, 1995a).

From the age of two years on, the development of the human prefrontal cortex relative to posterior sensory cortices continues to increase until about the age of twelve, although it increases at a much slower pace than in the first two years (Geidd et al., 1999; Huttenlocher and Dabholkar, 1997). This gradual, relative expansion of the prefrontal cortex is accompanied by the similarly gradual, progressive influence of frontal feedback moving caudally as the child passes through its next two developmental cognitive stages, the "concrete" operations and the "formal" operations stages. The concrete operations stage, beginning around the age of six years, is identified mostly with what Piaget referred to as a "decentering" of the child's cognitive processes insofar as the child begins to distinguish its "self" and accordingly its perspectives from those of others (Noack, 2006b). Part and parcel of this decentering process is the ability of the child to "conserve" physical properties in the universe, such as lengths and volumes, in that it begins to understand that certain physical properties can remain intact *as a concept* even though they may undergo some transformation. According to the frontal feedback model, this process of decentering in the

child corresponds to a moderately strong frontal feedback effect whereby the frontal driving influence prevents the influence of bottom–up transformations in sensory stimuli from affecting category attractor representations in posterior sensory-association cortices. This guarding of the integrity of the category attractors in the face of bustling transformations in sensory field activity provides for the phenomenon of conservation and of a sense of self (see below).

Finally, the formal operations stage, beginning around the age of twelve years, is identified mostly with abstract thought. According to the frontal feedback model, abstract thought is a phenomenon that is created when strong frontal feedback driving influence extends caudally in the cortex deep toward primary sensory areas. This strong frontal feedback driving influence essentially prevents chaotic attractors in these early sensory cortices from easily falling into previously learned attractors by creating high-dimensional activity there (see Part 1). Such high-dimensional activity allows for the formation of abstract sensory field representations (objects and environments) which can be maintained for a period of time until the created scenario produces some reward value, at which point the created scenario will become stored as a memory. The concrete-operations brain, possessing weaker frontal feedback, does not have this ability because the created scenarios rapidly fall into existing attractor states, reflecting *actual* sensorimotor events the child has previously encountered. Thus, the concrete-operations brain is essentially bound to manipulating only real world events whereas the formal-operations brain can create fictitious, abstract events (Noack, 1995a).

Experimental Predictions

Using as a guide the dynamic causal modeling framework discussed above (outlined in the Mechelli et al. [2003, 2004] studies) as well as the concepts of the frontal feedback model discussed so far, some predictions can begin to be made as to what type of activity might be found in the developing child's brain upon examination. The first prediction is that the strength of the rostro–caudal, or top–down, driving activity seen in the Mechelli et al. studies during cognitive/imaginative processes will be relatively weak in pre-adolescent children. In pre-operational children 2–6 years of age, this top–down component of activity will be especially weak, gradually increasing in strength only as the child moves through adolescence and then into adulthood. A second prediction is that neo-natal infants in the sensorimotor stage of development (>1.5–2 years) will demonstrate a conspicuous lack of this top–down component altogether, exhibiting an almost exclusive robust bottom–up, or feedforward, component of cortical driving activity. Accordingly, it is also predicted that essentially all nonpongid primate and mammalian species in general will similarly lack the top–down component of driving activity seen in the

Mechelli et al. studies, exhibiting mainly a robust feedforward dynamic.[4] As far as pongid species (chimpanzee, gorilla, and orangutan) are concerned, the question remains open as several studies have suggested some limited pre-operational abilities in these species (see Parker and McKinney, 1999). Therefore, some or all of these nonhuman pongid species may display limited top–down driving activity, although the strength of that driving would be very weak if it did, indeed, exist.

The Frontal Feedback System and the Production of the Human Mind

In Part 1 of this paper, a neurodynamic model for the function of the pre-human mammalian brain was outlined. In that model, it was the perception–action cycle that provided the mechanism and governing influence for the function of that brain. In the human, on the other hand, it is the frontal feedback system that provides the mechanism and governing influence in brain function. That system will be outlined below in some detail in an attempt to integrate the many concepts presented so far in this paper and in Part 1 into a model for the production of the human mind.

Frontal Feedback and the Creation of the Human Global Attractor

At any given moment, the nonhuman cerebral cortex manifests a global attractor. The shape of that global attractor is largely reflective of the sensory stimulation currently arriving in primary sensory cortex and of concurrent limbic influences coming from subcortical structures. These combined influences engage the animal in real time toward some immediate goal through initiating the process of chaotic itinerancy and, correspondingly, the perception–action cycle (see Part 1). In a general sense, then, it can be said that the shape of the nonhuman global attractor is mainly "stimulus bound," reflective only of the current environmental circumstance.

In the human brain, however, the situation is different. The shape of the human global attractor is reflective not only of sensory and limbic influences, but is mainly reflective of the sustained influence of the frontal motor routines on posterior sensory areas. Such a sustained frontal motor influence biases the human global attractor *to be engaged constantly in the act of creation* through the frontal cortex highly organizing the release and reconstruction of stored sensory cell assemblies in posterior cortices (Noack, 1995a). More specifically, the frontal motor routines "reach in" and shape a fictitious inter-

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[4]In the terminology of a series of studies discussed below (see Goldberg, Harel, and Malach, 2006; Golland et al., 2007), the human infant in the sensorimotor stage and all nonpongid mammalian species will display a conspicuous lack of an "intrinsic" system.

nal landscape in posterior sensory areas through the re-excitation and internal manipulation of sensory cell assemblies there.

Frontal Feedback, Action–Schemes, and the Category Attractor

In order to understand how frontal feedback constructs a fictitious landscape in posterior cortices, it is necessary to return once again to the concepts of the action–scheme, the background attractor, consensus in the triggering of a cell assembly, and the category attractor discussed in Part 1. The first important point to consider is the proposition put forth here that the main functional utility of the continued expansion of sensory-association areas in "higher" mammals was to facilitate the greater and greater elaboration of categorical associations among sensory stimuli across the various sense domains. These categorical associations in the cortex form as the multitude of sensory impressions in posterior cortex become conditioned to specific behavior patterns. What results is the formation of a multitude of category attractors in posterior sensory cortex, each of which is associated with and, in essence, is *defined* by a particular action–scheme. In fact, the only reason categorical associations and, thus, category attractors, form at all is through their association with a particular action–scheme. In this way, the multitude of sensory impressions arriving from the environment can be shaped and categorized in accordance with some specific behavior with which to negotiate those sensory impressions. For example, thousands of individual sensory representations may participate in the formation of a category attractor related to foods to consume. This "foods to consume" category attractor then becomes defined by an associated consummatory action–scheme in the frontal cortex. The subsequent presentation of any one of those thousands of representative food items would then have the effect of triggering that single consummatory action–scheme. In short, sensory-association areas serve to group sensory information into a format where quick, appropriate responses can be generated in the presence of a highly complex, dynamic sensory environment. Again, such an effect is indicative of the nonhuman perception–action cycle.

In the nonhuman brain, it is only the effects of sensory stimuli and limbic influences that trigger the category attractors described above. In the human brain, however, the action–schemes, which define these category attractors, may also, through frontal feedback, trigger these category attractors. The effect that an action–scheme has on the triggering of a category attractor is quite different than that produced by sensory stimuli. That is, whereas the detail of a sensory stimulus will ordinarily trigger a specific representation, or wing, of the category attractor, an action–scheme will have a more general and ambiguous effect on the activity of the category attractor. For example, from the bottom–up direction the sight of a soda bottle may trigger a category

attractor in posterior cortex related to "objects to drink out of" but will specifically trigger the wing of that category attractor related to soda bottles. In contrast to that scenario, the top–down release in frontal cortex of the action–scheme (task-oriented attractor [see Part 1]) involved in "grabbing an object off the table and taking a drink out of it" will, through frontal feedback, simply trigger the *general* category attractor of "objects to drink out of." The specific wing of that attractor that is realized in this situation is relatively arbitrary since there is no specific sensory stimulus present that might reveal (unlock) a wing, or basin, to force the attractor into. What results is simply the general excitation of this category attractor along with many or all of its constituent wings, resulting in brief, local, high-dimensional activity reflective of the many nascent cell assemblies (wings) competing for influence.

At this point, one of two scenarios may unfold. In the first scenario, the category attractor simply "falls" into one of its existing wings, reflecting the memory of a specific event that actually happened in the past, such as drinking out of a soda bottle, a coffee cup, a beer mug, etc. This scenario is the one that almost invariably unfolds during the concrete operations period of the development of the frontal feedback system and does so due to a relatively weak frontal feedback driving effect. However, this scenario is also common in the adult formal operations brain insofar as the frontal feedback system can modulate its effects on posterior cortices if the simple recall of an actual past occurrence is desirable (it stimulates reward centers).

In the second scenario, the frontal action–scheme triggering of a posterior category attractor actually drives the synthesis of a novel, fictitious experience. This scenario happens almost exclusively in the formal operations brain and is the result of a strong frontal feedback driving effect on posterior sensory cortex. That is, the high-dimensional activity that results from the strong excitation of a category attractor through the influence of frontal feedback is synonymous with the presentation of a novel sensory stimulus in posterior cortices (see Skarda and Freeman, 1987). A novel sensory stimulus acts to store itself as a memory from the bottom–up direction by destabilizing the sensory cortices/category attractors long enough to build a novel cell assembly/attractor that is representative of itself (provided that that destabilization is accompanied by sufficient reward activity). A strong frontal feedback driving influence has an effect similar to the presentation of a novel sensory stimulus in that it destabilizes the area of cortex housing the sensory category attractors long enough to provide for the creation of novel, fictitious sensory constructs. Provided, then, that these "internally created" sensory constructs confer some reward value in limbic structures, these constructs will be stored just as if they had actually occurred in the environment since both real and the imagined scenarios are played out on the same posterior sensory cortex (Halpern and Zatorre, 1999; Halpern, Zatorre, Bouffard, and Johnson, 2004; Kosslyn, 2005;

Slotnick, Thompson, and Kosslyn, 2005). The frontal feedback system provides a sustained influence on this posterior cortex with the hierarchically sequenced nature of the action–schemes providing a temporal structure to such creative synthesis that is not found in the nonhuman brain. Thus, the human brain can do what the nonhuman brain cannot: create fictitious classes of sensory stimuli and thus novel category attractors.

The scenarios described above do not only pertain to category attractors representing specific classes of objects, but more generally to the entire environment in which the human is embedded, thus reflecting the internal creation of fictitious environments and objects that interact in these environments. The manifestation of these processes will be discussed shortly. First, however, it is necessary to look more specifically at how the frontal feedback system is organized and operates.

Frontal Feedback and the Creation of the Central Character and Virtual World

To restate, the main functional utility of the frontal feedback system is its ability to create and synthesize fictitious sensory scenarios in posterior cortex. What essentially results from this synthesis is the creation of a virtual environment, or virtual world, in posterior sensory cortex, a world that is organized and maintained by the frontal feedback system. Interestingly, what becomes immediately apparent during the synthesis of this virtual world is that there is an "object of relativity" against which that world is being created and manipulated. That object of relativity is embedded within this virtual world in that the object of relativity interacts with other objects and is subject to the same physical laws, or transformational relations, that all other objects are subject to. Thus, this object of relativity in effect becomes regarded as the "central character" in this created virtual world, a world that is continuously evolving, a story that is continuously unfolding. In short, the central character emerges *within* the virtual world, which pivots about the central character and interacts with it via the action of the frontal feedback system.

One interesting feature of the concept of the central character is that its location can actually be generalized anatomically in the cortex. The focus of the central character's representation lies at the highest levels of sensory processing in posterior sensory cortex, the so-called "multi-modal" association areas of the parieto–temporal cortex (see Pandya and Yeterian [1985] for homologous regions in monkeys). These areas are targeted because (1) they accept the most complete representations of the human's polymodal sensory environment and (2) they receive dense direct feedback projections from prefrontal cortex. Therefore, parieto–temporal cortex is the *principal avenue* through which the virtual world is created by the frontal feedback system. Accordingly, the effects of frontal feedback begin in this region and, from there, feed down the line toward more primary sensory areas. The central

character is created right at the beginning, at the highest levels of polymodal convergence, since it is these regions that house the most complete polymodal representations of the created virtual world. In fact, it is precisely this integrated polymodal representation in parieto–temporal cortex that identifies the central character. More specifically, *the central character is defined as the continual, simultaneous, spatio–temporal evolution of these integrated polymodal representations in parieto–temporal association cortex.* The activity that extends from these regions down the line toward more primary sensory areas becomes the "extension" of that central character, namely the environment or virtual world within which that character resides.

In short, then, the virtual world exists only as an extension of the central character; it cannot exist independently of it. Thus, the central character's relation to its virtual world is a phenomenon that is created from the *inside-out*, so to speak. The phenomenon of parietal neglect illustrates this point. Damage to the areas of cortex where the central character resides (sensory-association areas) not only *ablates* the representation of the central character in contralateral space; it also ablates the entire virtual world associated with the central character in that side of space. In left-side neglect, it is not just the awareness of the individual's left visual field that is lacking: it is the individual's entire *concept* of the left half of the individual's world that is missing (Becchio and Bertone, 2005; Bisiach and Luzzatti, 1978; Carter, 2002; Venneri and Shanks, 2004). The individual does not understand this reality simply because that part of the universe does not exist for him or her. Additional evidence relating the focus of the central character to these association regions comes from studies showing that these are the main regions of cortex that become active during cognitive tasks that require a focused attention on how the central character/self is relating to its virtual world (Baars, Ramsoy, and Laureys, 2003; Vogeley and Fink, 2003; Vogeley, May, Ritzl, Falkai, Zilles, and Fink, 2004).

Frontal Feedback and the Production of the Sense of Self

According to the frontal feedback model, a distinction is made within the virtual world between the central character and its external environment because the central character comes to associate the physical boundary of its skin with a unique object within the virtual world. Since that unique object represents the object of relativity for which the entire virtual world is created, that unique object comes to be identified as a "self," which acts into and perceives from this virtual world (the concept of the central character and the self are synonymous with one another and will be used interchangeably from here on). The key to understanding why this distinction occurs is to look again at how the frontal feedback system works, which is by associating a particular species of sensory representation as an object and then by proceeding to manip-

ulate that object via an action–scheme. The physical boundary of human skin (and the collection of experiences associated with it) is simply regarded by the frontal feedback system as one object among many in its larger created virtual world (Noack, 1995a), and its (the body's) manipulation in that world is an *automatic* effect of the functioning of the frontal feedback system.

To summarize, the appearance of frontal feedback in the human brain had a profound effect in that it created the internal concept of a central character and an internal environment in which that character resides. In the next section, we will see how the frontal feedback system works to represent the individual interacting with its environment and its cognitive functions.

Shifting Boundaries of Frontal Feedback and Human Experience

The virtual world created by the frontal feedback system outlined above represents only half the process involved in creating the human's conscious experience. In actuality, the entirety of the human's virtual world is both a *composite* of top–down frontal feedback activity and concurrent bottom–up influences from the sensory environment. That is, as the influence of frontal feedback is pushing down the line from polymodal toward primary sensory areas, activity from the sensory systems is simultaneously pushing up the line from primary toward polymodal areas. These competing influences collide somewhere in the middle, the dynamics of which reflects our ongoing conscious experience.

Cognition and Imagination

At times of rest, when significant stimuli are not present, activity from the frontal feedback system "bleeds" from higher sensory-association areas toward earlier sensory cortices, the effect of which reflects our internal cognitive thought processes and our imagining of fictitious events. In that space, the central character is being manipulated inside a fictitious environment created by the frontal feedback system. Again, the central character is created at the highest level of polymodal abstraction (parieto–temporal cortex), and the created world in which it is embedded exists in cortical areas more toward primary sensory cortex. It is in these earlier sensory cortical spaces that the elements of imaginative and cognitive manipulation are created. That is, as frontal feedback activity bleeds to these lower areas, less "evolved" representations of objects can be created and manipulated, such as coffee cups, pencils, tools, sporting equipment, or some novel, fictitious object. Cognition occurs through the highest representation of the sensory systems in polymodal cortex (the central character/self) manipulating lower levels of sensory representation (e.g., coffee cups, pencils, and representations of the central character's limbs) through the strong influence of frontal feedback in the human brain.

One of the objects that the frontal feedback system creates and manipulates in these earlier cortices is a representation of the central character itself. Again, this is a result of the frontal feedback system coming to identify the physical body it is housed in as simply another object in its created virtual world. This is a special object, however, and the process of the central character manipulating a created representation of itself in these lower sensory cortices provides for the phenomenon of "self-awareness." In fact, the frontal feedback system can create many of these self-representations and manipulate them in a variety of fashions, yielding dialogs among them and giving rise to "metaperspectives." Empathy can be achieved through the frontal feedback system assigning similar self-aware properties to other human individuals, animals, and even otherwise inanimate objects (Noack, 1995a), yielding the development of a "theory of mind." Ultimately, the processes described above can take the common form of the central character imagining itself drinking a cup of coffee, skiing the Alps, walking on a distant planet, fixing its car, engaging in dialog with another "non-central" character, and so on.

The Self Interacting With an Object (Sensory Perception)

A second scenario sees the strong top–down influence of frontal feedback diminish in the presence of a significant sensory stimulus. In this scenario, the imagined events described in the previous section will disappear as bottom–up sensory input pushes the effects of frontal feedback more toward later association cortices as important sensory stimuli enter the sensory streams. What essentially happens in this case is that the internally created world suddenly vanishes as lower sensory-association areas act instead to represent the immediate environmental circumstance. This occurs primarily because the significance of the sensory stimulus acts to mobilize subcortical systems involved in reward or punishment to reinforce the stimuli's presence and influence in cortical dynamics. Thus, the "zone of collision" between feedforward (bottom–up) and feedback (top–down) activity pushes rostrally toward higher polymodal sensory cortex, and the central character finds itself interacting with concurrent sensory influences instead of created sensory scenarios in the same lower-level sensory-association cortex.[5] Such interaction is manifested in human experience as the self perceiving an object (sensory stimulus) in that the "sub-

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[5]It is important to note that the zone of collision is not necessarily a *hard* boundary separating bottom–up from top–down influences, but rather a *soft* boundary indicating which influence holds more sway over cortical dynamics at that level of the processing stream. Both bottom–up and top–down influences likely pass through each other in opposite directions, their effects over cortical dynamics being largely attenuated in cortical areas further upstream or downstream the opposite end of the boundary. Even with this qualification, though, the idea of a general dynamic boundary is helpful in conveying the essential dynamical features of the frontal feedback system outlined here.

ject" of human experience is largely housed in these earlier sensory cortical spaces. In the above scenario, those early spaces are occupied with the representation of current sensory stimuli. It is important to note, however, that due to strong frontal feedback influences in humans, most forms of sensory stimulation are not powerful enough to routinely invade the later association regions of the sensory processing stream, which represent the central character (see next section for exceptions), leaving, in most instances, the integrity of the central character unaffected. This property of frontal feedback is important because it confers a consistency of identity to that central character.

Being "In the Zone" and Animal Consciousness

A third scenario sees frontal feedback disappearing altogether at times if the current sensory stimulation is of extreme importance. Most of us have had the experience of being so thoroughly engrossed in the current moment that we seem to "lose ourselves" in the event. Athletes often refer to such occasions as being "in the zone" in that the person's mechanical interaction with the environment is so complete and real time that there is no time or room for any reflection on what the individual is doing. Interestingly, such occasions may provide us a brief experiential glimpse into what a purely feedforward system and, thus, "animal consciousness" may be like. Again, though, while this in-the-zone state is the typical scenario in nonhumans, it is a relatively infrequent event in humans, and, once that urgent sensory stimulus is removed, activity in the frontal feedback system would again push back down the hierarchy, bleeding toward earlier sensory cortices as we return to our cogitations.

Recently, this in-the-zone state has been investigated by researchers, who have identified two anti-correlated systems within the neocortex of the human (Goldberg et al., 2006; Golland et al., 2007; see also Fox, Snyder, Vincent, Corbetta, Van Essen, and Raichle, 2005). One system, known as the "extrinsic" system, comes online when the individual is engaged in a significant or attention-demanding sensory situation, such as watching an absorbing movie. The other system, the "intrinsic" system, comes online when urgent sensory information is removed and the individual begins to reflect on the experience or otherwise engages in introspective/cognitive related tasks (Goldberg et al., 2006; Golland et al., 2007). What is interesting about these studies for the present discussion is that the activation of one system appears to deactivate the other system (hence, anti-correlated). Thus, what these researchers found was that when experimental subjects were presented with significant and attention-demanding stimuli, they tended to lose the capacity for introspection or "lose themselves" in the event as would be predicted from the dynamical features of the frontal feedback system described above. What is also interesting and relevant to the present discussion is that the anatomical areas composing

the intrinsic system seem to overlap closely with the regions argued here to constitute the core of the frontal feedback system (see above).

Another important contribution the Goldberg et al. (2006) and Golland et al. (2007) studies make to the present discussion is that they help to highlight the ongoing manner in which the human brain functions during a given waking day. According to the frontal feedback model, there are two main functional systems in the human brain that regulate its behavior throughout the day. One system is mostly cortical in nature and is composed of the two anticorrelated networks described in the Goldberg et al. studies. This system is mostly associated with voluntary or "conscious" behaviors. The other system is mostly subcortical and early cortical in nature and is composed of a limbic–striatal–early cortical network such as the one outlined in Mishkin and Appenzeller (1987). This second system is mostly associated with "unconscious" or habit-type automatic behaviors such as riding a bike or driving a car.

During the normal "resting state" of the human, when a significant sensory event is not currently in progress, brain activity is characterized by robust activity in the intrinsic system and weak activity in the extrinsic system of the larger conscious cortical system described above. At the same time, the unconscious subcortical habit system would be carrying out routine behavioral repertoires. An example of such a resting state would be an individual driving to work in the morning and imagining what will be happening at a meeting taking place later in the day. If at some point, however, a car from the opposite direction veers into this individual's lane, the individual would snap out of his or her daydream and make a diversionary turn of the car. In this situation, the extrinsic system would now take over activity in the neocortex, inhibiting the intrinsic system and also possibly in effect overriding or facilitating the automatic subcortical system in order to make the diversionary turn. It is only after the driver feels that he or she has diverted an accident that the resting state of brain activity once again returns.

The Production of Conscious Experience in the Self

Put simply, the self "experiences" when there is some *change* in its global activity pattern, that is, change in activity in parieto–temporal association cortex. When the self is thinking or imagining, that change comes from the frontal cortex manipulating lower sensory cortices *through the parieto–temporal cortex* in a top–down fashion; the resulting experience reflects the projection of the self into the virtual world (environment). When the self is perceiving a sensory stimulus, that change comes from the activity of the stimulus *invading* parieto–temporal cortex in a bottom–up fashion; the resulting experience reflects the projection of the virtual world (environment) into the self.

The Constancy of Self and the Development of Personality

The perceived constancy of the self derives from the fact that it is infrequently in the state of being in the zone. It ordinarily oscillates between the two states of imagining and interacting with the environment. The larger, more abstract category attractors that compose the substrate of parieto–temporal cortex reflect, for the most part, the belief and value systems, or "personality," of the self and are slow to change relative to the more bustling and dynamic activity in earlier sensory cortices. One reason they are slow to change is that they are *guarded* from capricious environmental manipulation through the effects of frontal feedback, which is internally generated and which forms a relatively autonomous frontal feedback system. The category attractors that form in parieto–temporal cortex are formed *carefully* over long periods of time through the internally generated reflective activities of the frontal feedback system. Once these "higher" category attractors, and thus belief systems, form, they act to "color" our thought processes and also the perception of the events and the world around us. They do so in a top–down fashion by modulating the actions of frontal feedback into earlier posterior sensory cortices, and thus the manner in which we think. They do so in a bottom–up fashion by modulating the manner in which sensory stimulation is classified, and thus how we interpret the events that happen to us.

Although parieto–temporal association cortex is the center of the action when it comes to subjective experience, the physical manifestation of such experience is a *hemisphere-wide* event, and its physical substrate is the human global attractor described earlier. The shape of that attractor *reflects the positioning of the change in parieto–temporal cortex against that which is changing it or that which is changed through it*, and it is the entirety of this process, manifested in the resultant global attractor, that defines a subjective experience. For example, the self experiences a red coffee cup when activity in parieto–temporal cortex is positioned against the characteristic attractors for red in color-related cortex and for a coffee cup in object-related cortex. Again, the representation of the coffee cup simply reflects one wing of the more general category attractor (in earlier sensory cortex) of "objects to drink out of." The ability of the self to distinguish the coffee cup as a unique entity in its virtual world arises from the reliable attractor that emerges when that category attractor falls into the wing that represents the coffee cup. That process is accompanied by a correlative change in the shape of the attractor over parieto–temporal cortex, and, combined, the global, hemisphere-wide phase-locked attractor that results embodies the qualitative experience of the self perceiving a red cup.

Frontal Feedback and the Production of Human Sentient Experience

In addition to offering an explanation for the emergence of cognitive facul-ties in the human brain, the frontal feedback model also offers an explanation for the emergence of experiential phenomena in the human brain (Noack, 2004, 2006a). Known popularly as the "hard problem" (Chalmers, 1995, 2004), the emergence of conscious experience in the human brain can be explained simply by reviewing what it is that the feedback system does. In the frontal feedback system, there is a central character embedded within a creat-ed virtual world. The primary function of the frontal feedback system is to exploit this virtual world for the benefit of the central character. It does so by associating value with classes of stimuli (e.g., objects) and by producing behaviors through which to negotiate those stimuli to some end that will ben-efit the central character (i.e., maintain its homeostasis). The assumption is that the biological success of the central character in its virtual world will cor-respond to the organism's success in the actual world.

To restate the above in more general terms, the primary focus of human brain function is the manipulation of the central character within its virtual world in order to increase its biological success or fitness. In light of this, it is principally important that this central character have as many tools at its dis-posal as possible in order to deal effectively with a sometimes difficult and hostile world. Many of these tools the human inherited through phylogeny, namely a strong, flexible, self-repairing and disease-fighting body (Freeman, 1995). In addition, the human inherited a rich and detailed representation of its sensory environment through the continued phylogenetic expansion of posterior sensory cortical areas earlier in its history. The importance of the phylogenetic development of these sensory systems is that it continued to confer on the organism a greater and greater ability to *distinguish* stimuli. Organisms that are able to distinguish among a large number of complex stim-uli are in a better position to find mates, find food, avoid predators, and so forth (Jerison, 1973).

In conclusion, then, it is proposed here that it was the necessity of the cen-tral character/self to make distinctions among stimuli that eventually yielded the phenomena of sentient experience in humans. That is, each stimulus the central character is able to distinguish as a unique entity represents another tool it has at its disposal to survive and flourish in its virtual world. In order to distinguish the various facets of this virtual world, the central character has to *experience* them as different from one another. If the central character/self did not experience the properties of its world as different, it would not be able to manipulate or use them simply because *those properties would not exist* in its virtual world. They have to be able to be distinguished in order to exist. Thus, *sentient or conscious experience is defined as the process whereby the central char-*

acter makes distinctions within its virtual world. This ability to distinguish allows the central character to categorize and classify different forms of information in its world: the activity representative of the color red, of hunger, of pain, of ecstasy, of wetness, etc. It allows the central character to associate words with these experiences in order to more effectively distinguish them and manipulate them internally through language. In short, sentient or conscious experience in the human is the brain's way of telling the central character what is happening to it.

Some Final Thoughts on the Hard Problem and Explanatory Gap

Understanding the production of conscious experience in humans as the method whereby the central character makes distinctions within its virtual world holds many advantages over the traditional reductionist approach to the problem of consciousness. The reductionist approach is embodied in a wide variety of current consciousness models that attempt to *equate* consciousness with a single physical process. The particular physical process in question varies with the particular model (see Goertzal, 1992; Goswami, 1990; John, 2001; McFadden, 2002; Penrose, 1994; Pocket, 2002), but virtually all the models hold the common assumption that some sort of coherence effect in neural tissue embodies the conscious moment. This is, of course, a conceptually elegant idea, but it seems to create more problems than solutions. One problem is that, since coherence effects in neural tissue are found in virtually every nervous system (Prechtl, Bullock, and Kleinfeld, 2000; Prechtl, von der Emde, Wolfart, Karamursel, Akoev, Andrianov, and Bullock, 1998; Swanson, 2003) especially mammals (Freeman, 1995), then the assumption is that all animals are conscious to some extent. While this may or may not be the case, equating consciousness with coherence tells us little about how our human experience may be different from that of a rat or toad and, therefore, has little explanatory power. A second problem is that these reductionist models have obvious difficulties crossing the "explanatory gap" in their explanation of how such a single, unified physical process translates into rich, sentient experience (Chalmers, 1995, 2004). If we assume that physical processes are insentient and experiential processes are sentient, then we obviously cannot cross this gap. Sentience and insentience are mutually exclusive *by definition.* Therefore, attempting to explain consciousness "on the cheap" (Chalmers, 1995) by artificially forcing a correlation between a physical process and a conscious moment will always fail to satisfy scientific curiosity.

The frontal feedback model overcomes the above-mentioned problems posed by the hard problem and explanatory gap because it makes no unnecessary assumptions about how physical matter is *supposed* to behave or what "emergent" properties should or should not arise from that behavior. Instead,

the frontal feedback model offers what is argued here to be an equally valid nonreductionist (see Chalmers, 1995, 2004) explanation of the production of conscious experience, one whereby the phenomena is explained as an evolutionary adaptation with a biologically selective advantage. This approach at least offers a reason for the existence of consciousness, using what we know today about the nature of brain function and physical processes, the continued inquiry into which may lead to a better theory.

Conclusion

In the course of primate brain evolution, the great phylogenetic expansion of the human frontal lobe effectively reversed the preferred direction of information flow in the human cerebral cortex. This reversal provided for the identification of a unique object of relativity, or central character, in posterior parieto–temporal cortex, along with the creation of a unified virtual world in which that central character was embedded. Through the action of frontal motor areas on posterior sensory areas, this central character then began to undergo incessant manipulation within this virtual environment, yielding a continuously unfolding virtual saga. This property of human neocortical function succeeded in producing complex cognitive abilities, self-awareness, and sentient experience in humans.

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