Consciousness, Intentionality, and Causality

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Abstract

To explain how stimuli cause consciousness, we have to explain causality. We can't trace linear causal chains from receptors after the first cortical synapse, so we use circular causality to explain neural pattern formation by self-organizing dynamics. But an aspect of intentional action is causality, which we extrapolate to material objects in the world. Thus causality is a property of mind, not matter.

Summary

1 According to behavioral theories deriving from pragmatism, Gestalt psychology, existentialism, and ecopsychology, knowledge about the world is gained by intentional action followed by learning. In terms of the neurodynamics described here, if the intending of an act comes to awareness through reafference, it is perceived as a cause. If the consequences of an act come to awareness through proprioception and exteroception, they are perceived as an effect. A sequence of such states of awareness comprises consciousness, which can grow in complexity to include self-awareness. Intentional acts do not require awareness, whereas voluntary acts require self-awareness. Awareness of the action/perception cycle provides the cognitive metaphor of linear causality as an agency. Humans apply this metaphor to objects and events in the world to predict and control them, and to assign social responsibility. Thus linear causality is the bedrock of social contracts and technology.

2 Complex material systems with distributed nonlinear feedback, such as brains and their neural and behavioral activities, cannot be explained by linear causality. They can be said to operate by circular causality without agency. The nature of self-control is described by breaking the circle into a forward limb, the intentional self, and a feedback limb, awareness of the self and its actions. The two limbs are realized through hierarchically stratified kinds of neural activity. Actions are governed by the self-organized microscopic neural activity of cortical and subcortical components in the brain. Awareness supervenes as

a macroscopic ordering state, that defers action until the self-organizing microscopic process has reached a closure in reflective prediction. Agency, which is removed from the causal hierarchy by the appeal to circularity, re-appears as a metaphor by which events in the world are anthropomorphized, making them subject to the illusion of human control.

1. Introduction

3 What is consciousness? It is known through experience of the activities of one's own body and observation of the bodies of others. In this respect the question whether it arises from the soul (Eccles, 1994), or from panpsychic properties of matter (Whitehead, 1938; Penrose, 1994; Chalmers, 1996), or as a function of brain operations (Searle, 1992; Dennett, 1991; Crick, 1994) is not relevant. The pertinent questions are - however it arises and is experienced - how and in what senses does it cause the functions of brains and bodies, and how do brain and body functions cause it? How do actions cause perceptions; how do perceptions cause awareness; and how do states of awareness cause actions? Analysis of causality is a necessary step toward a comprehension of consciousness, because the forms of answers depend on the choice among meanings that are assigned to "cause": (a) to make, move and modulate (an agency in linear causality); (b) to explain, rationalize and blame (cognition in circular causality without agency but with top-down-bottom-up interaction); or (c) to flow in parallel as a meaningful experience, by-product, or epiphenomenon (noncausal interrelation).

4 The elements of linear causality (a) are shown in Figure 1 in terms of stimulus-response determinism. A stimulus initiates a chain of events including activation of receptors, transmission by serial synapses to cortex, integration with memory, selection of a motor pattern, descending transmission to motor neurons, and activation of muscles. At one or more nodes along the chain, awareness occurs, and meaning and emotion are attached to the response. Temporal sequencing is crucial; no effect can precede or occur simultaneously with its cause. At some instant each effect becomes a cause. The demonstration of causal invariance must be based on repetition of trials. The time line is reinitiated at zero in observer time, and S-R pairs are collected. Some form of generalization is used. In the illustration it is by time ensemble averaging. Events with small variance in time of onset close to stimulus arrival are retained. Later events with varying latencies are lost. The double dot indicates a point in real time; it is artificial in observer time. This conceptualization is inherently limited, because awareness cannot be defined at a point in time.

5 The elements of circular causality (b) are shown in Figure 2. The double dot shows a point moving counterclockwise on a trajectory idealized as a circle, in order to show that an event exists irresolvably as a state through a period of inner time, which we reduce to a point in real time. Stimuli from the world impinge on this state. So also do stimuli arising from the self-organizing dynamics within the brain. Most stimuli are ineffective, but occasionally one

succeeds as a "hit" on the brain state, and a response occurs. The impact and motor action are followed by a change in brain structure that begins a new orbit.

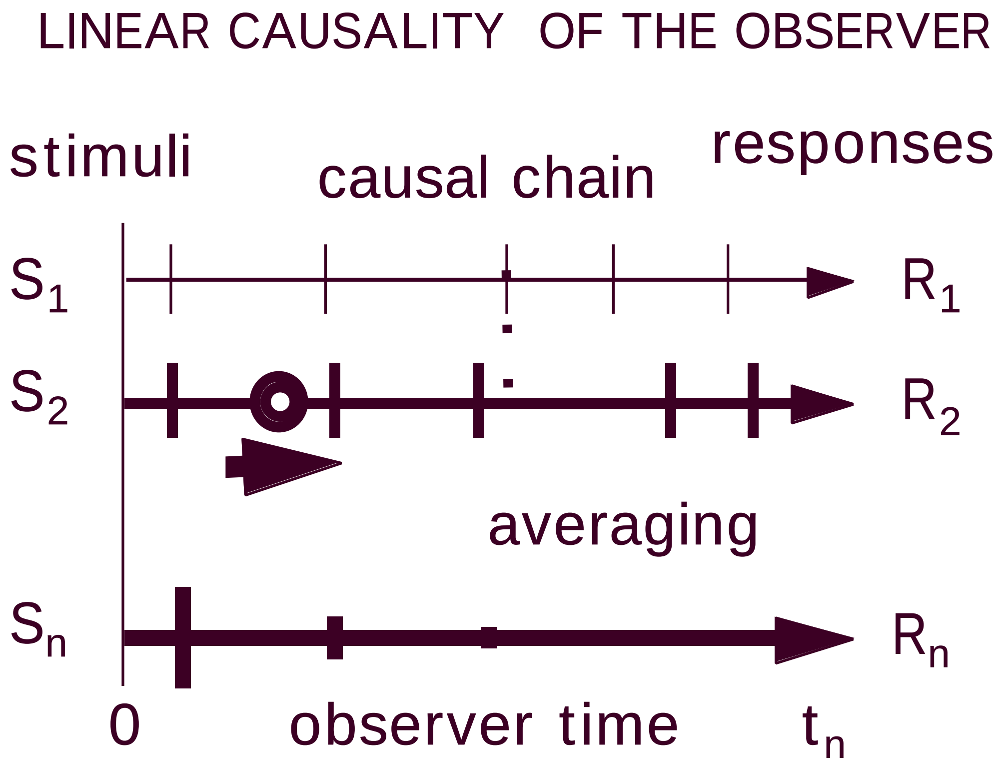

Figure 1. Linear causality is the view of connected events by which causal chains are constructed. The weaknesses lie in requirements to assign points in time to the beginning and the end of each chain, and to intervening events in the chain in strict order, and to repeat pairs of observations in varying circumstances in order to connect pairs of classes of events. As Davidson (1980) remarked, events have causes; classes have relations. In the example, analysis of stimulus-dependent events such as evoked potentials is done by time ensemble averaging, which degrades nonsynchronized events, and which leads to further attempts at segmentation in terms of the successive peaks, thus losing sight of an event extended in time. The notion of 'agency' is implicit in each event in the chain acting to produce an effect, which then becomes the next cause.

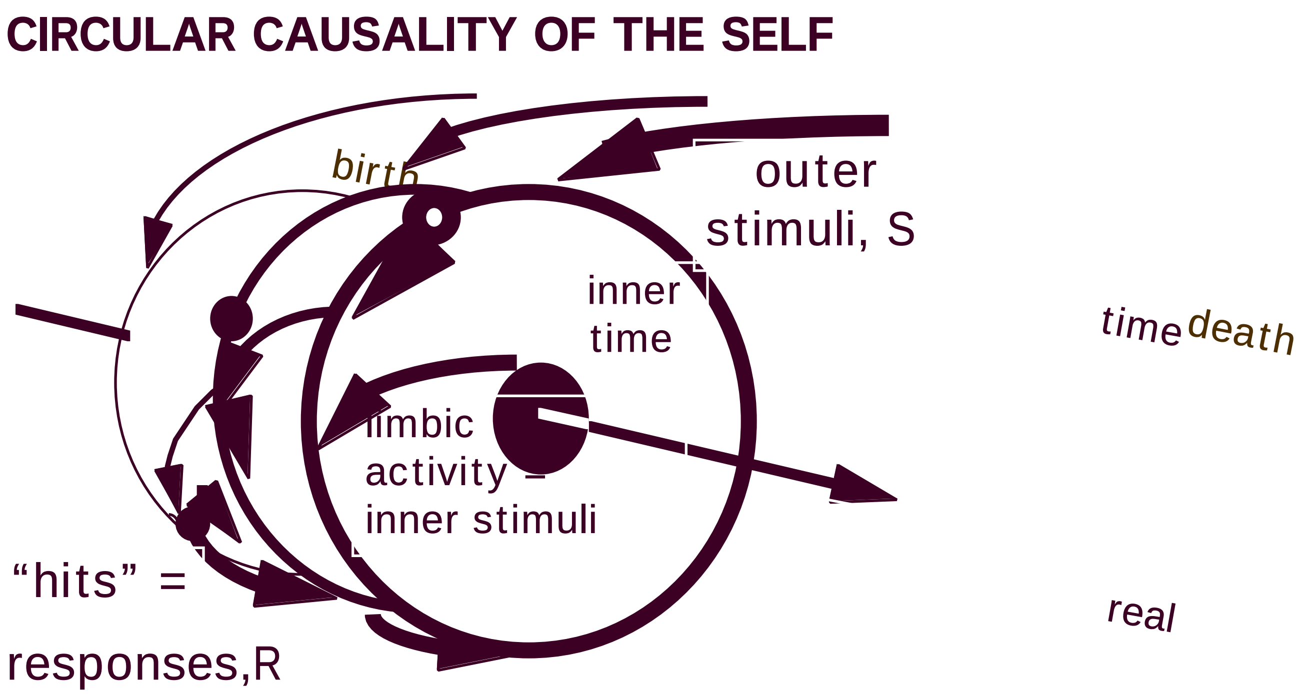

Figure 2. Circular causality expresses the interrelations between levels in a hierarchy: a top-down macroscopic state simultaneously influences microscopic particles that bottom-up create and sustain the macroscopic state. The state exists over a span of inner time in the system that can be collapsed to a point in external time. Events in real time are marked by changes in the state of the system, which are discrete. This conceptualization is widely used in the social and physical sciences. In an example used by Haken (1983), the excited atoms in a laser cause coherent light emission, and the light imposes order on the atoms. The laser was also used by Cartwright (1989) to exemplify levels of causality, by which she contrasted simple, direct cause-effect relations not having significant interactions or second-order perturbations with higher order "capacities" (according to her, closely related to Mill's "tendencies", but differing by "material abstraction", p. 226), which by virtue of abstraction have an enlarged scope of forward action, but which lack the circular relation between microscopic and macroscopic entities that is essential for explaining lasers - and brains. The notion of an 'agency' does not enter, and multiple scales of time and space are required for the different levels.

A succession of orbits can be conceived as a cylinder with its axis in real time, extending from birth to death of an individual and its brain. Events are intrinsically not reproducible. Trajectories in inner time may be viewed as fusing past and future into an extended present by state transitions. The circle is a candidate for representing a state of awareness.

6 Noncausal relations (c) are described by statistical models, differential equations, phase portraits, and so on, in which time may be implicit or reversible. Once the constructions are completed by the calculation of risk factors and degrees of certainty from distributions of observed events and objects, the assignment of causation is optional. In describing brain functions awareness is treated as irrelevant or epiphenomenal.

7 These concepts are applied to animal consciousness on the premiss that the structures and activities of brains and bodies are comparable over a broad variety of animals including humans. The hypothesis is that the elementary properties of consciousness are manifested in even the simplest of extant vertebrates, and that structural and functional complexity increases with the evolution of brains into higher mammals. The dynamics of simpler brains is described in terms of neural operations that provide goal-oriented behavior.

In the first half of this essay (Sections 2-6) I describe the neural mechanisms of intention and reafference and learning, as I see them. I compare explanations of neural mechanisms using linear and circular causality at three levels of hierarchical function. In the second half I describe some applications of this view in the fields of natural sciences. The materials I use to answer the question, what is causality?, come from several disciplines, including heavy reliance on neurobiology and nonlinear dynamics. In the words of computer technologists these two disciplines make up God's own firewall, which keeps hackers from burning in to access and crack the brain codes. For reviews on neuroflaming I recommend introductory texts by Bloom and Lazerson (1988) on "Brain, Mind and Behavior", and by Abraham et al. (1990) on "Visual Introduction to Dynamical Systems Theory for Psychology."

2. Level 1: The circular causality of intentionality

8 An elementary process requiring the dynamic interaction between brain, body and world in all animals is an act of observation. This is not a passive receipt of information from the world, as expressed implicitly in Figure 1. It is the culmination of purposive action by which an animal directs its sense organs toward a selected aspect of the world and abstracts, interprets, and learns from the resulting sensory stimuli (Figure 2). The act requires a prior state of readiness that expresses the existence of a goal, a preparation for motor action to position the sense organs, and selective sensitization of the sensory cortices. Their excitability has already been shaped by the past experience that is relevant to the goal and the expectancy of stimuli. A concept that can serve as a principle by which to assemble and interrelate these multiple facets is intentionality. This concept has been used in different contexts, since its synthesis by Aquinas (1272) 700 years ago. The properties of intentionality as

it is developed here are (a) its intent or directedness toward some future state or goal; (b) its unity; and (c) its wholeness (Freeman 1995).

9 (a) Intent comprises the endogenous initiation, construction, and direction of behavior into the world, combined with changing the self by learning in accordance with the perceived consequences of the behavior. Its origin lies within brains. Humans and other animals select their own goals, plan their own tactics, and choose when to begin, modify, and stop sequences of action. Humans at least are subjectively aware of themselves acting. This facet is commonly given the meaning of purpose and motivation by psychologists, because, unlike lawyers, they usually do not distinguish between intent and motive. Intent is a forthcoming action, and motive is the reason.

10 (b) Unity appears in the combining of input from all sensory modalities into *Gestalten*, in the coordination of all parts of the body, both musculoskeletal and autonomic, into adaptive, flexible, yet focused movements, and in the full weight of all past experience in the directing of each action. Subjectively, unity may appear in the awareness of self. Unity and intent find expression in modern analytic philosophy as "aboutness", meaning the way in which beliefs and thoughts symbolized by mental representations refer to objects and events in the world, whether real or imaginary. The distinction between inner image and outer object calls up a dichotomy between subject and object that was not part of the originating Thomistic view.

11 (c) Wholeness is revealed by the orderly changes in the self and its behavior that constitute the development and maturation of the self through learning, within the constraints of its genes and its material, social and cultural environments. Subjectively, wholeness is revealed in the striving for the fulfillment of the potential of the self through its lifetime of change. Its root meaning is "tending", the Aristotelian view that biology is destiny. It is also seen in the process of healing of the brain and body from damage and disruption. The concept appears in the description by a 14th century surgeon, LaFranchi of Milan, of two forms of healing, by first intention with a clean scar, and by second intention with suppuration. It is implicit in the epitaph of Ambroise Paré, 16th century French surgeon: "Je le pansay, Dieu le guarit" (I bound his wounds, God healed him). Pain is intentional in that it directs behavior toward facilitation of healing, and that it mediates learning when actions have gone wrong with deleterious, unintended consequences. Pain serves to exemplify the differences between volition, desire and intent; it is willed by sadists, desired by masochists, and essential for normal living.

12 Intentionality cannot be explained by linear causality, because actions under that concept must be attributed to environmental (Skinner, 1969) and genetic determinants (Herrnstein and Murray, 1994), leaving no opening for self-determination. Acausal theories (Hull, 1943; Grossberg, 1982) describe statistical and mathematical regularities of behavior without reference to intentionality. Circular causality explains intentionality in terms of "action-perception cycles" (Merleau-Ponty, 1945) and affordances (Gibson, 1979), in which each perception concomitantly is the outcome of a preceding action and

the condition for a following action. Dewey (1914) phrased the same idea in different words; an organism does not react to a stimulus but acts into it and incorporates it. That which is perceived already exists in the perceiver, because it is posited by the action of search and is actualized in the fulfillment of expectation. The unity of the cycle is reflected in the impossibility of defining a moving instant of 'now' in subjective time, as an object is conceived under linear causality. The Cartesian distinction between subject and object does not appear, because they are joined by assimilation in a seamless flow.

3. Level 2: The circular causality of reafference

13 Brain scientists have known for over a century that the necessary and sufficient part of the vertebrate brain to sustain minimal intentional action, a component of intentionality, is the ventral forebrain, including those parts that comprise the external shell of the phylogenetically oldest part of the forebrain, the paleocortex, and the underlying nuclei such as the amydala with which the cortex is interconnected. These components suffice to support identifiable patterns of intentional behavior in animals, when all of the newer parts of the forebrain have been surgically removed (Goltz, 1892) or chemically inactivated by spreading depression (Bures et al., 1974). Intentional behavior is severely altered or lost following major damage to these parts. Phylogenetic evidence comes from observing intentional behavior in salamanders, which have the simplest of the existing vertebrate forebrains (Herrick, 1948; Roth, 1987) comprising only the limbic system. Its three cortical areas are sensory (which is predominantly the olfactory bulb), motor (the pyriform cortex), and associational (Figure 3). The latter has the primordial hippocampus connected to the septal, amygdaloid and striatal nuclei. It is identified in higher vertebrates as the locus

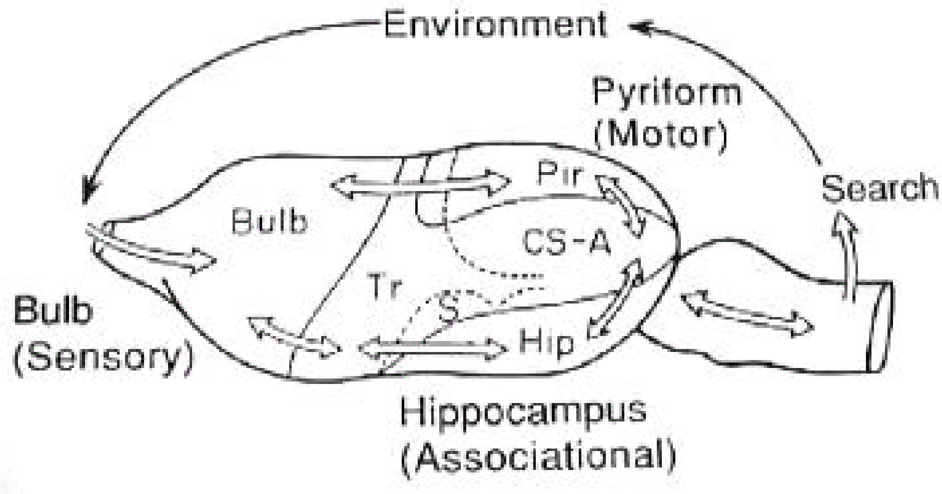

Figure 3. The schematic shows the dorsal view of the right cerebral hemisphere of the salamander (adapted from Herrick 1948). The unbroken sheet of superficial neuropil sustains bidirectional interactions between all of its parts, which are demarcated by their axonal connections with sensory receptors (olfactory bulb and 'Transitional zone' for all other senses, descending connections to the corpus striatum, amygdaloid and septum from the pyriform area, and the intrinsic connections between these areas and the primordial hippocampus posteromedially. This primitive forebrain suffices as an organ of intentionality, comprising the limbic system with little else besides.

of the functions of spatial orientation (the "cognitive map") and temporal orientation in learning ("short term memory"). These integrative frameworks are essential for intentional action into the world, because even the simplest actions, such as observation, searching for food or evading predators, require an animal to coordinate its position in the world with that of its prey or refuge, and to evaluate its progress during evaluation, attack or escape .

14 The crucial question for neuroscientists is, how are the patterns of neural activity that sustain intentional behavior constructed in brains? A route to an answer is provided by studies of the electrical activity of the primary sensory cortices of animals that have been trained to identify and respond to conditioned stimuli. An answer appears in the capacity of the cortices to construct novel patterns of neural activity by virtue of their self-organizing dynamics.

15 Two approaches to the study of sensory cortical dynamics are in contrast. One is based in linear causality (Figure 1). An experimenter identifies a neuron in sensory cortex by recording its action potential with a microelectrode, and then determines the sensory stimulus to which that neuron is most sensitive. The pulse train of the neuron is treated as a symbol to 'represent' that stimulus as the 'feature' of an object, for example the color, contour, or motion, of an eye or a nose in a face. The pathway of activation from the sensory receptor through relay nuclei to the primary sensory cortex and then beyond is described as a series of maps, in which successive representations of the stimulus are activated. The firings of the feature detector neurons must then be synchronized or 'bound' together to represent the object, such as a moving colored ball, as it is conceived by the experimenter. This representation is thought to be transmitted to a higher cortex, where it is compared with representations of previous objects that are retrieved from memory storage. A solution to the 'binding problem' is still being sought (Gray, 1994; Hardcastle, 1994; Singer and Gray, 1995).

16 The other approach is based in circular causality (Figure 2). In this view the experimenter trains a subject to cooperate through use of positive or negative reinforcement, thereby inducing a state of expectancy and search for a stimulus, as it is conceived by the subject. When the expected stimulus arrives, the activated receptors transmit pulses to the sensory cortex, where they elicit the construction by nonlinear dynamics of a macroscopic, spatially coherent oscillatory pattern that covers the entire cortex (Freeman, 1975, 1991). It is observed by means of the electroencephalogram (EEG) from electrode arrays on all the sensory cortices (Freeman, 1975, 1992, 1995; Barrie et al., 1996; Kay and Freeman 1998). It is not seen in recordings from single neuronal action potentials, because the fraction of the variance in the single neuronal pulse train that is covariant with the neural mass is far too small, on the order of 0.1%.

17 The emergent pattern is not a representation of a stimulus, nor a ringing as when a bell is struck, nor a resonance as when one string of a guitar vibrates when another string does so at its natural frequency. It is a phase transition that is induced by a stimulus, followed by a construction of a pattern that is shaped

by the synaptic modifications among cortical neurons from prior learning. It is also dependent on the brain stem nuclei that bathe the forebrain in neuromodulatory chemicals. It is a dynamic action pattern that creates and carries the meaning of the stimulus for the subject. It reflects the individual history, present context, and expectancy, corresponding to the unity and the wholeness of intentionality. Owing to dependence on history, the patterns created in each cortex are unique to each subject.

18 The visual, auditory, somesthetic and olfactory cortices serving the distance receptors all converge their constructions through the entorhinal cortex into the limbic system, where they are integrated with each other over time. Clearly they must have similar dynamics, in order that the messages be combined into Gestalten. The resultant integrated meaning is transmitted back to the cortices in the processes of selective attending, expectancy, and the prediction of future inputs (Freeman, 1995; Kay and Freeman, 1998).

19 The same wave forms of EEG activity as those found in the sensory cortices are found in various parts of the limbic system. This similarity indicates that the limbic system also has the capacity to create its own spatiotemporal patterns of neural activity. They are embedded in past experience and convergent multisensory input, but they are self-organized. The limbic system provides interconnected populations of neurons, that, according to the hypothesis being proposed, generate continually the patterns of neural activity that form goals and direct behavior toward them.

20 EEG evidence shows that the process in the various parts occurs in discontinuous steps (Figure 2), like frames in a motion picture (Freeman, 1975; Barrie, Freeman and Lenhart, 1996). Being intrinsically unstable, the limbic system continually transits across states that emerge, transmit to other parts of the brain, and then dissolve to give place to new ones. Its output controls the brain stem nuclei that serve to regulate its excitability levels, implying that it regulates its own neurohumoral context, enabling it to respond with equal facility to changes, both in the body and the environment, that call for arousal and adaptation or rest and recreation. Again by inference it is the neurodynamics of the limbic system, with contributions from other parts of the forebrain such as the frontal lobes and basal ganglia, that initiates the novel and creative behavior seen in search by trial and error.

21 The limbic activity patterns of directed arousal and search are sent into the motor systems of the brain stem and spinal cord (Figure 4). Simultaneously, patterns are transmitted to the primary sensory cortices, preparing them for the consequences of motor actions. This process has been called "reafference" (von Holst and Mittelstädt 1950; Freeman 1995), "corollary discharge" (Sperry 1950), "focused arousal", and "preafference" (Kay and Freeman, 1998). It compensates for the self-induced changes in sensory input that accompany the actions organized by the limbic system, and it sensitizes sensory systems to anticipated stimuli prior to their expected times of arrival.

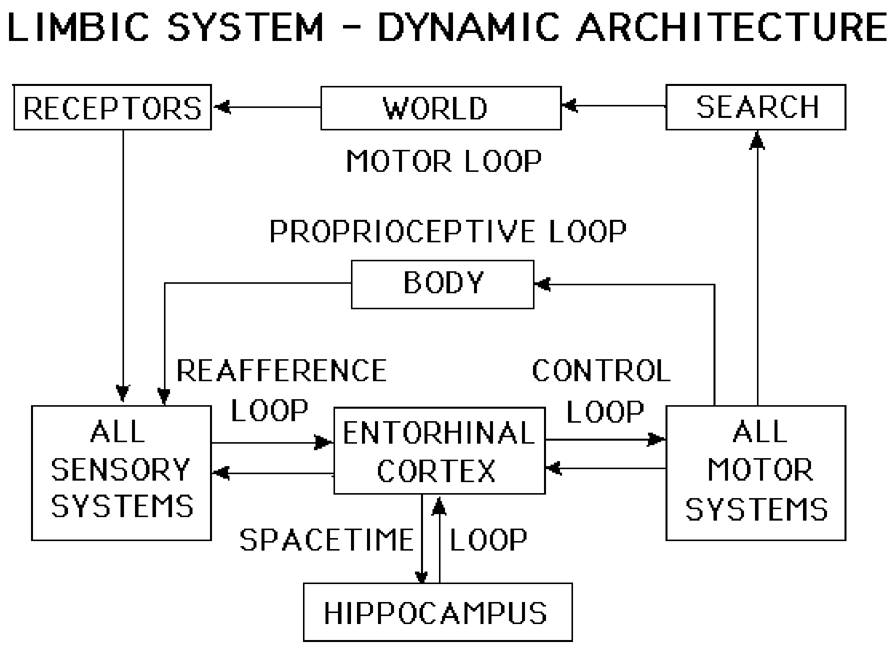

Figure 4. In the view of dynamics the limbic architecture is formed by multiple loops. The mammalian entorhinal cortex is the target of convergence of all sensory input, the chief source of input for the hippocampus, its principal target for its output, and a source of centrifugal input to all of the primary sensory cortices. The hypothesis is proposed that intentional action is engendered by counterclockwise flow of activity around the loops into the body and the world, comprising implicit cognition, and that awareness and consciousness are engendered by clockwise flow within the brain, comprising explicit cognition. The intentional flow consists in the microscopic activity of brain subsystems, and the back flow is the macroscopic order parameter that by circular causality regulates and holds or releases the activity of the subsystems.

22 The concept of preafference began with an observation by Helmholtz (1872) on patients with paralysis of lateral gaze, who, on trying and being unable to move an eye, reported that the visual field appeared to move in the opposite direction. He concluded that "an impulse of the will" that accompanied voluntary behavior was unmasked by the paralysis. He wrote: "These phenomena place it beyond doubt that we judge the direction of the visual axis only by the volitional act by means of which we seek to alter the position of the eyes.". J. Hughlings Jackson (1931) repeated the observation, but postulated alternatively that the phenomenon was caused by "an in-going current", which was a signal from the non-paralyzed eye that moved too far in the attempt to fixate an object, and which was not a recursive signal from a "motor centre". He was joined in this interpretation by William James (1893) and Edward Titchener (1907), thus delaying deployment of the concepts of neural feedback in re-entrant cognitive processes until late in the 20th century.

23 The sensory cortical constructions consist of brief staccato messages to the limbic system, which convey what is sought and the result of the search. After multisensory convergence, the spatiotemporal activity pattern in the limbic system is up-dated through temporal integration in the hippocampus. Accompanying sensory messages there are return up-dates from the limbic system to the sensory cortices, whereby each cortex receives input that has been integrated with the input from all others, reflecting the unity of intentionality. Everything that a human or an animal knows comes from the circular causality of action, preafference, perception, and up-date. It is done by successive frames of self-organized activity patterns in the sensory and limbic cortices.

4. Level 3: Circular causality among neurons and neural masses

24 The "state" of the brain is a description of what it is doing in some specified time period. A phase transition occurs when the brain changes and does something else. For example, locomotion is a state, within which walking is a rhythmic pattern of activity that involves large parts of the brain, spinal cord, muscles and bones. The entire neuromuscular system changes almost instantly with the transition to a pattern of jogging or running. Similarly, a sleeping state can be taken as a whole, or divided into a sequence of slow wave and REM stages. Transit to a waking state can occur in a fraction of a second, whereby the entire brain and body shift gears, so to speak. The state of a neuron can be described as active and firing or as silent, with sudden changes in patterns of firing constituting phase transitions. Populations of neurons also have a range of states, such as slow wave, fast activity, seizure, or silence. The science of dynamics describes states and their phase transitions.

25 The most critical question to ask about a state is its degree of stability or resistance to change. Stability is evaluated by perturbing an object or a system (Freeman 1975). For example, an egg on a flat surface is unstable, but a coffee mug is stable. A person standing on a moving bus and holding on to a railing is stable, but someone walking in the aisle is not. If a person regains his chosen

posture after each perturbation, no matter in which direction the displacement occurred, that state is regarded as stable, and it is said to be governed by an attractor. This is a metaphor to say that the system goes (" is attracted to") the state through interim transiency. The range of displacement from which recovery can occur defines the basin of attraction, in analogy to a ball rolling to the bottom of a bowl. If a perturbation is so strong that it causes concussion or a broken leg, and the person cannot stand up again, then the system has been placed outside the basin of attraction, and a new state supervenes with its own attractor and basin of attraction.

26 Stability is always relative to the time duration of observation and the criteria for what is chosen to be observed. In the perspective of a lifetime, brains appear to be highly stable, in their numbers of neurons, their architectures and major patterns of connection, and in the patterns of behavior they produce, including the character and identity of the individual that can be recognized and followed for many years. A brain undergoes repeated transitions from waking to sleeping and back again, coming up refreshed with a good night or irritable with insomnia, but still, giving arguably the same person as the night before. But in the perspective of the short term, brains are highly unstable. Thoughts go fleeting through awareness, and the face and body twitch with the passing of emotions. Glimpses of the internal states of neural activity reveal patterns that are more like hurricanes than the orderly march of symbols in a computer, with the difference that hurricanes don't learn. Brain states and the states of populations of neurons that interact to give brain function, are highly irregular in spatial form and time course. They emerge, persist for a small fraction of a second, then disappear and are replaced by other states.

27. Neuroscientists aim to describe and measure these states and tell what they mean both to observations of behavior and to experiences with awareness. We approach the dynamics by defining three kinds of stable state, each with its type of attractor. The simplest is the point attractor. The system is at rest unless perturbed, and it returns to rest when allowed to do so. As it relaxes to rest, it has a brief history, but loses it on convergence to rest. Examples of point attractors are neurons or neural populations that have been isolated from the brain, and also the brain that is depressed into inactivity by injury or a strong anesthetic, to the point where the EEG has gone flat. A special case of a point attractor is noise. This state is observed in populations of neurons in the brain of a subject at rest, with no evidence of overt behavior or awareness. The neurons fire continually but not in concert with each other. Their pulses occur in long trains at irregular times. Knowledge about the prior pulse trains from each neuron and those of its neighbors up to the present fails to support the prediction of when the next pulse will occur. The state of noise has continual activity with no history of how it started, and it gives only the expectation that its average amplitude and other statistical properties will persist unchanged.

28 A system that gives periodic behavior is said to have a limit cycle attractor. The classic example is the clock. When it is viewed in terms of its ceaseless motion, it is regarded as unstable until it winds down, runs out of power, and goes to a point attractor. If it resumes its regular beat after it is re-set or

otherwise perturbed, it is stable as long as its power lasts. Its history is limited to one cycle, after which there is no retention of its transient approach in its basin to its attractor. Neurons and populations rarely fire periodically, and when they appear to do so, close inspection shows that the activities are in fact irregular and unpredictable in detail, and when periodic activity does occur, it is either intentional, as in rhythmic drumming, or pathological, as in nystagmus and Parkinsonian tremor.

29 The third type of attractor gives aperiodic oscillation of the kind that is observed in recordings of EEGs and of physiological tremors. There is no one or small number of frequencies at which the system oscillates. The system behavior is therefore unpredictable, because performance can only be projected far into the future for periodic behavior. This type was first called "strange"; it is now widely known as "chaotic". The existence of this type of oscillation was known to mathematicians a century ago, but systematic study was possible only recently after the full development of digital computers. The best known simple systems with chaotic attractors have a small number of components and a few degrees of freedom, as for example, the double-hinged pendulum, and the dripping faucet. Large and complex systems such as neurons and neural populations are thought to be capable of chaotic behavior, but proof is not yet possible at the present level of developments in mathematics.

30 The discovery of chaos has profound implications for the study of brain function (Skarda and Freeman 1987). A dynamic system has a collection of attractors, each with its basin, which forms an 'attractor landscape' with all three types. The state of the system can jump from one to another in an itinerant trajectory (Tsuda 1991). Capture by a point or limit cycle attractor wipes clean the history upon asymptotic convergence, but capture in a chaotic basin engenders continual aperiodic activity, thereby creating novel, unpredictable patterns that retain its history.

31 Although the trajectory is not predictable, the statistical properties such as the mean and standard deviation of the state variables of the system serve as measures of its steady state. Chaotic fluctuations carry the system endlessly around in the basin. However, if energy is fed into the system so that the fluctuations increase in amplitude, or if the landscape of the system is changed so that the basin shrinks or flattens, a microscopic fluctuation can carry the trajectory across the boundary between basins to another attractor. This crossing constitutes a first order phase transition.

32 In each sensory cortex there are multiple chaotic attractors with basins corresponding to previously learned classes of stimuli, including that for the learned background stimulus configuration, which constitutes an attractor landscape. This chaotic prestimulus state of expectancy establishes the sensitivity of the cortex by warping the landscape, so that a very small number of sensory action potentials driven by an expected stimulus can carry the cortical trajectory into the basin of an appropriate attractor. Circular causality enters in the following way. The state of a neural population in an area of

cortex is a macroscopic event that arises through the interactions of the microscopic activity of the neurons comprising the neuropil. The global state is upwardly generated by the microscopic neurons, and simultaneously the global state downwardly organizes the activities of the individual neurons.

33 Each cortical phase transition requires this circularity. It is preceded by a conjunction of antecedents. A stimulus is sought by the limbic brain through orientation of the sensory receptors in sniffing, looking, and listening. The landscape of the basins of attraction is shaped by limbic preafference, which facilitates access to an attractor by expanding its basin for the reception of a desired class of stimuli. Preafference provides the ambient context by multisensory divergence. The web of synaptic connections modified by prior learning maintains the basins and attractors. Pre-existing chaotic fluctuations are enhanced by input, forcing the selection of a new macroscopic state that then engulfs the stimulus-driven microscopic activity.

34 The first proposed reason that all the sensory systems (visual, auditory, somatic and olfactory) operate this way is the finite capacity of the brain faced with the infinite complexity of the environment. In olfaction, for example, a significant odorant may consist of a few molecules mixed in a rich and powerful background of undefined substances, and it may be continually changing in age, temperature, and concentration. Each sniff in a succession with the same chemical activates a different subset of equivalent olfactory receptors, so the microscopic input is unpredictable and unknowable in detail. Detection and tracking require an invariant pattern over trials. This is provided by the attractor, and the generalization over equivalent receptors is provided by the basin. The attractor determines the response, not the particular stimulus. Unlike the view proposed by stimulus-response reflex determinism, the dynamics gives no linear chain of cause and effect from stimulus to response that can lead to the necessity of environmental determinism. The second proposed reason is the requirement that all sensory patterns have the same basic form, so that they can be combined into Gestalts, once they are converged to be integrated over time.

5. Circular causality in awareness

35 Circular causality, then, occurs with each phase transition in sensory cortices and the olfactory bulb, when fluctuations in microscopic activity exceed a certain threshold, such that a new macroscopic oscillation emerges to force cooperation on the very neurons that have brought the pattern into being. EEG measurements show that multiple patterns self-organize independently in overlapping time frames in the several sensory and limbic cortices, coexisting with stimulus-driven activity in different areas of the neocortex, which structurally is an undivided sheet of neuropil in each hemisphere receiving the projections of sensory pathways in separated areas.

36 Circular causality can serve as the framework for explaining the operation of awareness in the following way. The multimodal macroscopic patterns converge simultaneously into the limbic system, and the results of integration over time and space are simultaneously returned to all of the sensory systems.

Here I propose that another level of hierarchy exists in brain function as a hemispheric attractor, for which the local macroscopic activity patterns are the components. The forward limb of the circle provides the bursts of oscillations converging into the limbic system that destabilize it to form new patterns. The feedback limb incorporates the limbic and sensory cortical patterns into a global activity pattern or order parameter that enslaves all of the components. The enslavement enhances the coherence among all of them, which dampens the chaotic fluctuation instead of enhancing it, as the receptor input does in the sensory cortices.

37 A global operator of this kind must exist, for the following reason. The synthesis of sense data first into cortical wave packets and then into a multimodal packet takes time. After a Gestalt has been achieved through embedding in past experience, a decision is required as to what the organism is to do next. This also takes time for an evolutionary trajectory through a sequence of attractors constituting the attractor landscape of possible goals and actions (Tsuda, 1991). The triggering of a phase transition in the motor system may occur at any time, if the fluctuations in its multiple inputs are large enough, thereby terminating the search trajectory. In some emergent behavioral situations an early response is most effective: action without reflection. In complex situations with unclear ramifications into the future, precipitate action may lead to disastrous consequences. More generally, the forebrain appears to have developed in phylogenetic evolution as an organ taking advantage of the time provided by distance receptors for the interpretation of raw sense data. The quenching function of a global operator to delay decision and action can be seen as a necessary complement on the motor side, to prevent premature closure of the process of constructing and evaluating possible courses of action. This view is comparable to that of William James (1879), who wrote: " *...* the study *à posteriori* of the *distribution* of consciousness shows it to be exactly such as we might expect in an organ added for the sake of steering a nervous system grown too complex to regulate itself.", except that consciousness is not provided by another "organ" (an add-on part of the human brain) but by a new hierarchical level of organization of brain dynamics.

38 Action without the deferral that is implicit in awareness can be found in so-called 'automatic' sequences of action in the performance of familiar complex routines. Actions 'flow' without awareness. Implicit cognition is continuous, and it is simply unmasked in the conditions that lead to 'blindsight'. In this view, emotion is defined as the impetus for action, more specifically, as impending action. Its degree is proportional to the amplitude of the chaotic fluctuations in the limbic system, which appears as the modulation depth of the carrier waves of limbic neural activity patterns. In accordance with the James-Lange theory of emotion (James 1893), it is experienced through awareness of the activation of the autonomic nervous system in preparation for and support of overt action, as described by Cannon (1939). It is observed in the patterns of behavior that social animals have acquired through evolution (Darwin 1872). Emotion is not in opposition to reason. Behaviors that are seen as irrational and 'incontinent' (Davidson 1980) result from premature escape of the chaotic fluctuations from the leavening and smoothing of the awareness operator. The most intensely

emotional behavior, as it is experienced in artistic creation, scientific discovery, and religious awe, occurs as the intensity of awareness rises in concert with the strength of the fluctuations (Freeman 1995). As with all other difficult human endeavors, self-control is achieved through long and arduous practice.

39 Evidence for the existence of the postulated global operator is found in the high level of covariance in the EEGs simultaneously recorded from the bulb and the visual, auditory, somatic and limbic (entorhinal) cortices of animals and from the scalp of humans (Lehmann and Michel 1990). The magnitude of the shared activity can be measured in limited circumstances by the largest component in principle components analysis (PCA). Even though the wave forms of the several sites vary independently and unpredictably, the first component has 50-70% of the total variance (Smart et al., 1997; Gaál and Freeman, 1997). These levels are lower than those found within each area of 90-98% (Barrie, Freeman and Lenhart, 1996), but they are far greater than can be accounted for by any of a variety of statistical artefacts or sources of correlation such as volume conduction, pacemaker driving, or contamination by the reference lead in monopolar recording. The high level of coherence holds for all parts of the EEG spectrum and for aperiodic as well as near-periodic waves.

40 The maximal coherence appears to have zero phase lag over distances up to several centimeters between recording sites and even between hemispheres (Singer and Gray, 1995). Attempts are being made to model the observed zero time lag among the structures by cancellation of delays in bidirectional feedback transmission (König and Schillen, 1991; Traub et al. 1996; Roelfsma et al., 1997).

6. Consciousness viewed as a system parameter controlling chaos

41 A clear choice can be made now between the three meanings of causality proposed in the Introduction. Awareness and neural activity are not acausal parallel processes, nor does either make or move the other as an agency in temporal sequence. Circular causality is a form of explanation that can be applied at several hierarchical levels without recourse to agency. This formulation provides the sense or feeling of necessity that is essential for human comprehension, by addressing the elemental experience of cause and effect in acts of observation, even though logically it is very different from linear causality in all aspects of temporal order, spatial contiguity, and invariant reproducibility. The phrase is a cognitive metaphor. It lacks the attribute of agency, unless and until the loop is broken into the forward (microsocopic) limb and the recurrent (macroscopic) limb, in which case the agency that is so compelling in linear causality can be re-introduced. This move acquiesces to the needs of the human observers to use it in order to comprehend dynamic events and processes in the world.

42 I propose that the globally coherent activity, which is an order parameter, may be an objective correlate of awareness through preafference, comprising expectation and attention, which are based in prior proprioceptive and

exteroceptive feedback of the sensory consequences of previous actions, after they have undergone limbic integration to form Gestalts, and in the goals that are emergent in the limbic system. In this view, awareness is basically akin to the intervening state variable in a homeostatic mechanism, which is both a physical quantity, a dynamic operator, and the carrier of influence from the past into the future that supports the relation between a desired set point and an existing state. The content of the awareness operator may be found in the spatial pattern of amplitude modulation of the shared wave form component, which is comparable to the amplitude modulation of the carrier waves in the primary sensory receiving areas.

43 What is most remarkable about this operator is that it appears to be antithetical to initiating action. It provides a pervasive neuronal bias that does not induce phase transitions, but defers them by quenching local fluctuations (Prigogine, 1980). It alters the attractor landscapes of the lower order interactive masses of neurons that it enslaves. In the dynamicist view, intervention by states of awareness in the process of consciousness organizes the attractor landscape of the motor systems, prior to the instant of its next phase transition, the moment of choosing in the limbo of indecision, when the global dynamic brain activity pattern is increasing its complexity and fine-tuning the guidance of overt action. This state of uncertainty and unreadiness to act may last a fraction of a second, a minute, a week, or a lifetime. Then when a contemplated act occurs, awareness follows the onset of the act and does not precede it.

44 In that hesitancy, between the last act and the next, comes the window of opportunity, when the breaking of symmetry in the next limbic phase transition will make apparent what has been chosen. The observer of the self intervenes by awareness that organizes the attractor landscape, just before the instant of the next transition:

> Between the conception
> And the creation
> Between the emotion
> And the response
> Falls the Shadow
>
> Life is very long
>
> T. S. Eliot (1936) The Hollow Men

The causal technology of self-control is familiar to everyone: hold off fear and anger; defer closure; avoid temptation; take time to study; read and reflect on the opportunity, meaning, and consequences; take the long view as it has been inculcated in the educational process. According to Mill (1843): "We cannot, indeed, directly will to be different from what we are; but neither did those who are supposed to have formed our characters directly will that we should be what we are. Their will had no direct power except over their own actions. ... We are exactly as capable of making our own character, *if we will*, as others are of making it for us" (p. 550).

45 There are numerous unsolved problems with this hypothesis. Although strong advances are being made in analyzing the dynamics of the limbic system and its centerpieces, the entorhinal cortex and hippocampus (Boeijinga and Lopes da Silva, 1988; O'Keefe and Nadel, 1978; Rolls et al., 1989; McNaughton, 1993; Wilson and McNaughton, 1993; Buzsaki, 1996; Eichenbaum, 1997; Traub et al. 1996), their self-organized spatial patterns, their precise intentional contents and their mechanisms of formation in relation to intentional action are still unknown. The pyriform cortex to which the bulb transmits is strongly driven by its input, and it lacks the phase cones that indicate self-organizing capabilities comparable to those of the sensory cortices. Whether the hippocampus has those capabilities or is likewise a driven structure is unknown. The neural mechanisms by which the entire neocortical neuropil in each hemisphere maintains spatially coherent activity over a broad spectrum with nearly zero time lag are unknown. The significance of this coherent activity for behavior is dependent on finding correlates with behaviors, but these are unknown. If those correlates are meanings, then the subjects must be asked to make representations of the meanings in order to communicate them, so that they are far removed from overt behavior. Knowledge of human brain function is beyond the present reach of neurodynamics because our brains are too complex, owing to their mechanisms for language and self-awareness.

7. Causality belongs in technology, not in science

46. The case has now been made on the grounds of neurodynamics that causality is a form of knowing through intentional action. Thus causality is inferred not to exist in material objects, but to be assigned to them by humans with the intent to predict and control them. The determinants of human actions include not only genetic and environmental factors but self-organizing dynamics in brains, primarily operating through the dynamics of intentional action, and secondarily through neural processes that support consciousness, which is commonly but mistakenly attached to free will. While this inference is not new, it is given new cogency by recent developments in neuroscience. What, then, might be the consequences for natural science, philosophy, and medicine, if this inference is accepted?

47. The concept of causality is fundamental in all aspects of human behavior and understanding, which includes our efforts in laboratory experiments and the analysis of data to comprehend the causal relations of world, brain and mind. In my own work I studied the impact on brain activity of stimuli that animals were trained to ignore or to respond to, seeking to determine how the stimuli might cause new patterns of brain activity to form, and how the new patterns might shape how the animals behaved in response to the stimuli. I attempted to interpret my findings and those of others in terms of chains of cause and effect, which I learned to identify as 'linear causality' (Freeman 1975).

48. These attempts repeatedly foundered in the complexities of neural activity and in the incompatibility of self-organized, goal-directed behavior of my

animals with behaviorist models based on input-output determinism. I found that I was adapting to the animals at least as much as they were being shaped by me. My resort to acausal correlation based in multivariate statistical prediction was unsatisfying. Through my readings in physics and philosophy I learned the concept of 'circular causality', which invokes hierarchical interactions of immense numbers of semiautonomous elements such as neurons, which form nonlinear systems.. These exchanges lead to the formation of macroscopic population dynamics that shapes the patterns of activity of the contributing individuals. I found this concept to be applicable at several levels, including the interactions between neurons and neural masses, between component masses of the forebrain, and between the behaving animal and its environment, under the rubric of intentionality (Freeman 1995).

49. By adopting this alternative concept I changed my perspective (Freeman 1995). I now sought not to pin events at instants of time, but to conceive of intervals at differing time scales; not to fill the gaps in the linear chains, but to construct the feedback pathways from the surround; not to average the single responses to monotonously repeated stimuli, but to analyze each event in its uniqueness before generalizing; not to explain events exclusively in terms of external stimuli and context, but to allow for the contribution of self-organizing dynamics.

50. Circular causality departs so strongly from the classical tenets of necessity, invariance, and precise temporal order that the only reason to call it that isto satisfy the human habitual need for causes The most subtle shift is the disappearance of agency, which is equivalent to loss of Aristotle's efficient cause. Agency is a powerful metaphor. For examples, it is common sense to assert that an assassin causes a victim's death; that an undersea quake causes a tsunami; that a fallen tree causes a power failure by breaking a transmission line; that an acid-fast bacillus causes tuberculosis; that an action potential releases transmitter molecules at a synapse; and so forth. But interactions across hierarchical levels do not make sense in these terms. Molecules that cooperate in a hurricane cannot be regarded as the agents that cause the storm. Neurons cannot be viewed as the agents that make consciousness by their firing.

51. The very strong appeal of agency to explain events may come from the subjective experience of cause and effect that develops early in human life, before the acquisition of language, when as infants we go through the somatomotor phase (Piaget 1930; Thelen and Smith 1994) and learn to control our limbs and to focus our sensory receptors. "I act (cause); therefore I feel (effect)." Granted that causality can be experienced through the neurodynamics of acquiring knowledge by the use of the body, the question I raise here is whether brains share this property with other material objects in the world. The answer I propose is that assignment of cause and effect to one's self and to others having self-awareness is entirely appropriate, but that investing insensate objects with causation is comparable to investing them with teleology and soul.

52. The further question is: Does it matter whether or not causality is assigned to objects? The answer here is: very much. Several examples are given of scientific errors attributable to thinking in terms of linear causality. The most important, with wide ramifications, is the assumption of universal determinacy, by which the causes of human behavior are limited to environmental and genetic factors, and the causal power of self-determination is excluded from scientific consideration. We know that linear extrapolation often fails in a nonlinear world. Proof of the failure of this inference is by *reductio ad absurdum*. It is absurd in the name of causal doctrine to deny our capacity as humans to make choices and decisions regarding our own futures, when we exercise the causal power that we experience as free will.

8. Anthropocentricity in acts of human observation

53. Our ancestors have a history of interpreting phenomena in human terms appropriate to the scales and dynamics of our brains and bodies. An example of our limitations and our cognitive means for surmounting them is our spatial conception of the earth as flat. This belief is still quite valid for lengths of the size of the human body, such as pool tables, floors, and playing fields, where we use levels, transits, and gradometers, and even for distances that we can cover by walking and swimming. The subtleties of ships that were hull-down over the horizon were mere curiosities, until feats of intellect and exploration such as circumnavigation of the earth opened a new spatial scale. Inversely, at microscopic dimensions of molecules flatness has no meaning. Under an electron microscope the edge of a razor looks like a mountain range.

54. In respect to time scales, we tend to think of our neurons and brains as having static anatomies, despite the evidence of continual change from time lapse cinematography, as well as the cumulative changes that passing decades reveal to us in our bodies. An intellectual leap is required to understand that form and function are both dynamic, differing essentially in our time scales of measurements and experiences with them. The embryological and phylogenetic developments of brains are described by sequences of geometric forms and the spatiotemporal operations by which each stage emerges from the one preceding. The time scales are in days and eons, not in seconds as in behavior and its neurophysiological correlates.

55. The growth of structure and the formation of the proper internal axonal and dendritic connections is described by fields of attraction and repulsion, with gradient descents mediated by contact sensitivities and the diffusion of chemicals. Moreover, recent research shows that synapses undergo a process of continual dynamic formation, growth and deletion throughout life (Smythies, 1997). The same and similar terms are used in mathematics and the physical sciences such as astronomy and cosmology, over a variety of temporal and spatial scales, many of which are far from the scales of kinesthesia to which we are accustomed. On the one hand, morphogenesis is the geometry of motion, which we can grasp intuitively through time lapse photography. On the other hand, the motions of speeding bullets and hummingbird wings are revealed to us by high-speed cinematography.

56. The attribution of intention as a property of material objects was common in earlier times by the assignment of spirits to trees, rocks, and the earth. An example is the rising sun. From the human perspective the sun seems to ascend above the horizon and move across the sky. In mythology this motion was assigned to an agency such as a chariot carrying the sun, or to motivation by the music of Orpheus, because music caused people to dance. In the Middle Ages the sun, moon, planets and stars were thought to be carried by spheres that encircled the earth and gave ineffable music as they rotated. The current geometric explanation is that an observer on the earth's surface shifts across the terminator with inertial rotation in an acausal space-time relation. Still, we watch the sun move.

57. Similarly, humans once thought that an object fell because it desired to be close to the earth, tending to its natural state. In Newtonian mechanics it was pulled down by gravity. In acausal, relativistic terms, it follows a geodesic to a minimal energy state. The Newtonian view required action at a distance, which was thought to be mediated by the postulated quintessence held over from Aristotle, the "ether". Physicists were misled by this fiction, which stemmed from the felt need for a medium to transmit a causal agent. The experimental proof by Michaelson and Morley that the ether did not exist opened the path to relativistic physics and an implicit renunciation of gravitational causality. But physicists failed to pursue this revolution to its completion, and instead persisted in the subject-object distinction by appealing to the dependence of the objective observation on the subjective reference frame of the observer.

58. In complex, multivariate systems interactive at several levels like brains, causal sequences are virtually impossible to specify unequivocally. Because it introduced indeterminacy, evidence for feedback in the nervous system was deliberately suppressed in the first third of the 20th century. It was thought that a neuron in a feedback loop could not distinguish its external input from its own output. An example was the reaction of Ramón y Cajal to a 1929 report by his student, Rafael Lorente de Nó, who presented Cajal with his Golgi study of neurons in the entorhinal cortex (Freeman 1984). He constructed diagrams of axodendritic connections among the neurons with arrows to indicate the direction of transmission, and he deduced that they formed feedback loops. Cajal told him that his inference was unacceptable, because brains were deterministic and could not work if they had feedback. He withdrew his report from publication until Cajal died in 1934. After he published it (Lorente de Nó 1934), it became an enduring classic, leading to the concept of the nerve cell assembly by its influence on Donald Hebb (1949), and to neural networks and digital computers by inspiring Warren McCulloch and through him John von Neumann (1958). The concept of linear causality similarly slowed recognition and acceptance of processes of self-organization in complex systems, by the maxim that "nothing can cause itself." The phrase "self-determination" was commonly regarded as an oxymoron. A similar exclusion delayed acceptance of the concept of reafference, also called corollary discharge (Freeman 1995).

9. Applications in philosophy

59. Description of a linear causal connection is based on appeal to an invariant relationship between two events. If an effect follows, the cause is sufficient; if an effect is always preceded by it, then the cause is necessary. From the temporal order and its invariance, as attested by double-blind experimental controls to parcellate the antecedents, an appearance of necessity is derived. The search concludes with assignment of an agency, that has responsibility for production, direction, control or stimulation, and that has its own prior agency, since every cause must also be an effect.

60. According to David Hume (1739), causation does not arise in the events; it emerges in the minds of the observers. The temporal succession and spatial contiguity of events that are interpreted as causes and effects comprise the invariant connection. It is the felt force of conjoined impressions that constitutes the quale of causality. Since the repetition of these relations adds no new idea, the feeling of the necessity has to be explained psychologically. He came to this conclusion from an abstract premiss in the doctrine of the nominalism, according to which there are no universal essences in reality, so the mind cannot frame a concept or image that corresponds to any universal or general term, such as causality. This was opposed, then as now, to the doctrine of scientific realism. Hume and his nominalist colleagues were anticipated 500 years earlier by the work of Aquinas (1272), who conceived that the individual forms of matter are abstracted by the imagination ("phantasia") to create universals that exist only in the intellect, not in matter. Early 20th century physicists should have completed the Humeian revolution in their development of quantum mechanics, but they lost their nerve and formulated instead the Copenhagen interpretations, which reaffirmed the subject-object distinction of Plato and Descartes, despite the force of their own discoveries staring them in the face. Phenomenologists before Heidegger maintained the error, and postmodern structuralists persist in it. For example, instead of saying, "Causality is a form of knowing", they say, "The attribution of causality is a form of knowing." That is, "Causality really does exist in matter, but it is a matter of choice by humans whether to believe it."

61. Conversely, John Stuart Mill (1873) accepted "the universal law of causation" but not necessity. "... the doctrine of what is called Philosophical Necessity" weighed on my existence like an incubus. ... I pondered painfully on the subject, till gradually I saw light through it. I perceived, that the word Necessity, as a name for the doctrine of Cause and Effect applied to human action, carried with it a misleading association; and that this association was the operative force in the depressing and paralyzing influence which I had experienced" (pp. 101-102). He developed his position fully in "A System of Logic" (1843).

62. Kant (1781) insisted that science could not exist without causality. Since causality was for him a category in mind, it follows that science is a body of knowledge about the world but is not in the world. Causality then becomes a basis for agreement among scientists regarding the validation of relationships between events, and the prediction of actions to be taken for control of events in

the world. Since it could not be validated by inductive generalization from sense data, but was nevertheless essential to give wholeness and completion to experience [Apperzeption], Kant concluded that it must be "a priori" and "transcendental" over the sense data. This led him to designate causality as a category [Kategorien] in and of the mind, along with space and time as the forms of perception [Anschauungsformen], by which the sense data were irretrievably modified during assembly into perceptions, making the real world [Ding an sich] inaccessible to direct observation.

63. Friedrich Nietzsche (1886) placed causality in the mind as the expression of free will: "The question is in the end whether we really recognize the will as efficient, whether we believe in the causality of the will: if we do -- and at bottom our faith in this is nothing less than our faith in causality itself -- then we have to make the experiment of positing the causality of the will hypothetically as the only one ... the will to power" (p. 48).

64. Putnam (1990) assigned causality to the operation of brains in the process of observation: "Hume's account of causation ... is anathema to most present-day philosophers. Nothing could be more contrary to the spirit of recent philosophical writing than the idea that there is nothing more to causality than regularity or the idea that, if there is something more, that something more is largely subjective." (p. 81) "If we cannot give a single example of an ordinary observation report which does not, directly or indirectly, presuppose causal judgments, then the empirical distinction between the "regularities" we "observe" and the "causality" we "project onto" the objects and events involved in the regularities collapses. Perhaps the notion of causality is so primitive that the very notion of observation presupposes it?" [p. 75]

65. A case was made by Davidson (1980) for "anomalous monism" to resolve the apparent contradiction between the deterministic laws of physics, the necessity for embodiment of mental processes in materials governed by those fixed laws, and the weakness of the "laws" governing psychophysical events as distinct from statistical classes of events: "Why on earth should a cause turn an action into a mere happening and a person into a helpless victim? Is it because we tend to assume, at least in the arena of action, that a cause demands a causer, agency and agent? So we press the question; if my action is caused, what caused it? If I did, then there is the absurdity of an infinite regress; if I did not, I am a victim. But of course the alternatives are not exhaustive. Some causes have no agents. Among these agentless causes are the states and changes of state in persons which, because they are reasons as well as causes, constitute certain events free and intentional actions." [p. 19]

66. His premisses have been superceded in two respects. First, he postulated that brains are material systems, for which the laws of physics support accurate prediction. He described brains as "closed systems". In the past three decades numerous investigators have realized that brains are open systems, as are all organs and living systems, with an infinite sink in the venous return for waste heat and entropy, so that the 1st and 2nd laws of thermodynamics do not hold for brains, thus negating one of his two main premisses. Second, he postulated

that, with respect to meaning, minds are "open" systems, on the basis that they are continually acting into the world and learning about it. The analyses of electrophysiological data taken during the operations of sensory cortices during acts of perception indicate that meaning in each mind is a closed system, and that meaning is based in chaotic constructions, not in information processing, thus negating the other of his two main premisses. In my view, neurons engage in complex biochemical operations that have no meaning or information in themselves, but inspire meaning in researchers who measure them. The degree of unpredictability of mental and behavioral events is in full accord with the extent of variations in the space-time patterns of the activity of chaotic systems, thus removing the requirement for the adjective, "anomalous", because it applies to both sets of laws for the material and mental aspects of living systems. Moreover, the adoption of the concept "circular causality" from physics and psychology removes agency. That which remains is "dynamical monism".

10. Applications of causality in medical technology

67. Causality is properly attributed to intentional systems, whose mechanisms of exploring, learning, choosing, deciding, and acting constitute the actualization of the feeling of necessary connection, and of the cognitive metaphor of agency. It is properly used to describe technological intervention into processes of the material world after analysis of the interrelations of events. Surmounting linear causal thinking may enable neuroscientists to pursue studies in the dynamics of the limbic system to clarify the meanings of statistical regularities in chaotic, self-organizing systems and change their outcomes by experimental manipulation. Social scientists may take advantage of the discovery of a biological basis for choice and individual responsibility to strengthen our social and legal institutions by complementing environmental and genetic linear causation. The nature-nurture debate has neglected a third of the determinant triad: the self People can and do make something of themselves. Neurophilosophers studying consciousness in brain function may find new answers to old questions by re-opening the debate on causality. What acausal relations arise among the still inadequately defined entities comprising brains? What is the global operator of consciousness? The mind-brain problem is not solved, but it can be transplanted to more fertile ground.

68. My proposal is not to deny or abandon causality, but to adapt it as an essential aspect of the human mind/brain by virtue of its attachment to intentionality. This can be done by using the term "circular causality" divorced from agency in the sciences, and the term "linear causality" in combination with agency in the technologies, including medical, social, legal, and engineering applications.

69. For example, medical research is widely conceived as the search for the causes of diseases and the means for intervention to prevent or cure them. A keystone in microbiology is expressed in Koch's Postulates, which were formulated in 1881 by Robert Koch to specify the conditions that must be met, in order to assign a causal relation between a microorganism and a disease:

> (1) the germ must always be found in the disease; (2) it must be isolated in pure culture from the diseased individual; (3) inoculation with the isolated culture must be followed by the same disease in a suitable test animal; and (4) the same germ must be isolated in pure culture from the diseased test animal.

70. These postulates have served well for understanding transmissible diseases and providing a biological foundation for developing chemotherapies, vaccines, and other preventatives. Public health measures addressing housing, nutrition, waste disposal and water supplies had already been well advanced in the 19th century for the prevention of pandemics such as cholera, typhoid, tuberculosis, and dysentery, on the basis of associations and to a considerable extent the maxim, "Cleanliness is next to Godliness". This was intentional behavior of a high order indeed. The new science brought an unequivocal set of targets for research on methods of prevention and treatment.

71. The most dramatic development in neuropsychiatry was the finding of spirochetes in the brains of patients with general paresis, for which the assigned causes had been life styles of dissolution and moral turpitude. The discovery of the "magic bullet" 606 (arsphenamine) established the medical model for management of neuropsychiatric illness, which was rapidly extended to viruses (rabies, polio, measles), environmental toxins (lead, mercury, ergot), vitamin and mineral deficiencies (cretinism, pellagra), hormonal deficits (hypothyroidism, diabetic coma, lack of dopamine in postencephalitic and other types of Parkinson's disease), and genetic abnormalities (phenylketonuria, Tourette's and Huntingdon's chorea). Massive research programs are under way to find the unitary causes and the magic bullets of chemotherapies, replacement genes, and vaccines for Alzheimer's, neuroses, psychoses, and schizophrenias. The current explanations of the affective disorders -- too much or too little dopamine, serotonin, etc. -- resemble the Hippocratic doctrine of the four humors, imbalances of which were seen as the causes of diseases.

72. There are compelling examples of necessary connections. Who can doubt that the vibrio causes cholera, or that a now eradicated virus caused small pox? However, these examples come from medical technology, in which several specific conditions hold. First, the discoveries in bacteriology came through an extension of human perception through the microscope to a new spatial scale. This led to the development by Rudolf Virchow of the cellular basis of human pathology. The bacterial adversaries were then seen as having the same spatial dimensions as the cells with which they were at war. The bacterial invaders and the varieties of their modes of attack did not qualitatively differ from the macroscopic predators with which mankind had always been familiar, such as wolves and crocodiles, which humans eradicate, avoid, or maintain in laboratories and zoos. Second, the causal metaphor motivated the application of controlled experiments to the isolation and analysis of target bacterial and viral species, vitamins, toxic chemicals, hormones, and genes. It still does motivate researchers, with the peculiar potency of intermittent reinforcement by occasional success. The latest example is the recognition that pyloric ulcers

are caused by a bacillus and not by psychic stress or a deleterious life style, implying that the cause is "real" and not just "psychosomatic". Third, the research and therapies are directly addressed to humans, who take action by ingesting drugs and seeking vaccinations, and who perceive changes in their bodies thereafter. A feeling of causal efficacy is very powerful in these circumstances, and many patients commit themselves without reservation to treatments, well after FDA scientists by controlled studies have shown them to be ineffective. The urgency of conceptualizing causality to motivate beneficial human actions does not thereby establish the validity of that agency among the objects under study. Feeling is believing, but it is not knowing. The feeling of causal agency in medicine has led to victories, but also to mistakes with injury and death on a grand scale.

73. Koch's postulates approach a necessary connection of a bacillus to an infectious disease, but not the sufficient conditions. Pathogens are found in healthy individuals as well, and often not in the sick. Inoculation does not always succeed in producing the disease. These anomalies can be, and commonly are, ignored, if the preponderance of evidence justifies doing so, but the classical criteria for causality are violated, or are replaced with statistical judgments. A positive culture of a bacillus is sufficient reason to initiate treatment with an antibiotic, even if it is the wrong disease. Similarly, pathologists cannot tell the cause of death from their findings at autopsy. They are trained to state what the patient died "with" and not "of". It is the job of the coroner or a licensed physician to assign the cause of death. The causes of death are not scientific. They are social and technological, and they concern public health, economic well being, and the apprehension of criminals.

74. Another example of the social value of causality is the statement: "Smoking causes cancer." This is a clear and valid warning that a particular form of behavior is likely to end in early and painful death. On the one hand, society has a legitimate interest in maintaining health and reducing monetary and emotional costs by investing the strong statistical connection with the motivating status of causality. On the other hand, the "causal chain" by which tobacco tars are connected to the unbridled proliferation of pulmonary epithelial tissue is still being explored, and a continuing weakness of evidence for the complete linear causal chain is being used by tobacco companies to claim that there is no proof that smoking causes cancer. Thus the causal argument has been turned against society's justifiable efforts to prevent tobacco-related illnesses.

11. The Technology of Mental Illness

76. The most complex and ambiguous field of medicine concerns the causes and treatments of mental disorders. Diagnosis and treatment for the past century have been polarized between the medical model of the causes of diseases, currently held in biological psychiatry, and psychoanalysis, the talking cure. Sigmund Freud was impressed with the phenomena of hysteria, in which patients suffered transient disabilities, such as blindness and paralysis, but presented no evidence of infection or anatomical degeneration in their brains. He drew on his background in clinical neurology to develop a biological

hypothesis (1895) for behavior, based on the flow of nerve energy between neurons through "contact barriers" (3 years later named synapses by Foster and Sherrington). Some axonal pathways developed excessive resistance at these barriers, deflecting nerve energy into unusual channels by "neuronic inertia", giving rise to hysterical symptoms. Within a decade he had abandoned the biological approach as "premature", working instead with his symbolic model of the id, ego, and superego, but his ideas were generalized to distinguish "functional" from "organic" diseases. Traumatic childhood experiences warped the development of the contact barriers. Treatment was to explore the recesses of memory, bring the resistances to awareness, and reduce them by client and therapist reasoning together following transference and countertransference.

77. The bipolarization between the organic and the functional has been stable for a century. Patients and practitioners have been able to choose their positions in this spectrum of causes according to their beliefs and preferences. Some patients are delighted to be informed that their disorders are due to chemical imbalances, that are correctable by drugs and are not their fault or responsibility. Others bitterly resent the perceived betrayal by their bodies, and they seek healing through the exercise of mental discipline and the power of positive thinking. But the balance has become unstable with two new circumstances. One is the cost of medical care. Health maintenance organizations are pressuring psychiatrists to see more patients in shorter visits, to dispense with oral histories and the meanings of symptoms for the patients, and to get them quickly out the door with packets of pills. The power of biological causality is clearly in operation as a social, not a scientific, impetus, operating to the detriment of people with complex histories and concerns.

78. The other circumstance is the growing realization among mental health care specialists that chemical imbalances, poor genes, and unfortunate experiences of individuals are insufficient explanations to provide the foundations for treatment. Of particular importance for onset, course, and resolution of illnesses are the social relations of individuals, their families, neighborhoods, religious communities, and milieu of national policies and events. Current conflicts rage over the assignment of the cause of chronic fatigue syndrome to neuroticism or to a virus; of the Gulf War syndrome to malingering or a neurotoxin; of post-traumatic stress disorder to battle fatigue or a character deficit. The dependence of the debates on causality is fueled by technological questions of human action: what research is to be done, what treatments are to be given, and who is to pay for them? Successful outcomes are known to depend less on pills and counseling than on mobilization of community support for distressed individuals (Frankl, 1973). These exceedingly complex relations, involving faith and meaning among family and friends, may be seriously violated by reduction to unidirectional causes. Patients may be restored to perfect chemical balance and then die anyway in despair. Families may disintegrate into endless recrimination and self-justification, from lack of tolerance of misdirected parental and filial intentions and honest mistakes. So it is with patient-doctor relations. To seek and find a cause is to lay the blame, opening the legal right to sue for compensation for psychological injury and distress. These, too, are legacies of linear causal thinking.

79. Abnormal behavior in states of trance or seizure was attributed in past centuries to the loss or willing surrender of self-control to possession by exotic spirits. In the West the failure of responsibility was codified as legal insanity in 1846 according to the McNaughton Rule: "[To] establish a defense on the grounds of insanity, it must be clearly proven that at the time of the committing of the act, the party accused was labouring under such a defect of reason, from disease of the mind, as not to know the nature and quality of the act he was doing, or, if he did know it, that he did not know he was doing what was wrong." In the terms of the present analysis, for behavior to be insane the neural components of the limbic system must have entered into basins of attraction that are sufficiently strange or unusually stable to escape control by the global state variable. This view encompasses the two facets of causality, microscopic and macroscopic, that compete for control of the self, but it is not an adequate statement of the problem. In fact the case on which the Rule was based was decided on political grounds (Moran 1981). Daniel McNaughton was a Scotsman engaged in ideal-driven assassination, and his transfer by the British authorities from Newgate Prison to Bethlam Hospital was designed to prevent him from testifying in public. A similar move for similar reasons was made by the American government by sending the poet Ezra Pound, charged with treason in World War II, to St. Elizabeth's Hospital instead of the Leavenworth. The point is that judgments about which acts are intentional and which are not are made by society, in last resort by judges and juries in courts of law, not by doctors, scientists, or individuals in isolation. What biology can offer is a foundation on which to construct a social theory of self-control.

12. The science *versus* the technology of self-control

80. The role of causality in self-awareness is close to the essence of what it is to be human. Nowhere is this more poignant than in the feeling of the need for self-control. Materialists and psychoanalysts see the limbic self as a machine driven by metabolic needs and inherited instincts, the id, that carries the ego as a rational critic that struggles to maintain causal control, as befits the Cartesian metaphor of the soul serving as the pilot of a boat, by adjudicating blind forces. Structure and chemistry are genetically determined. Behaviorist psychologists confuse motivation with intention and view behavior as the sum of reflexes, caused by environmental inputs and sociobiological processes, while consciousness is epiphenomenal.

81. Functionalists see the mind as equivalent to software that can be adapted to run on any platform, once the algorithms and rules have been discovered. Logical operations on symbols as representations are the causes of rational behavior, and the unsolved problems for research concern the linkage of the symbols with activities of neurons and with whatever the symbols represent in the world. That research will be unnecessary, if the linkages can made instead to the components of intelligent machines resembling computers (Fodor 1981). Unfortunately the only existing intelligent beings have evolved from lower species, and our brains contain the limbic system as irrational baggage. Outputs from the logic circuits in the neocortex, before reaching the motor

apparatus, are filtered through the limbic system, where emotions are attached that distort and degrade the rational output. Consciousness is a mystery to be explained by 'new laws of physics' (Penrose 1994; Chalmers 1996).

82. Existentialists hold that humans choose what they become by their own actions. The cause of behavior is the self, which is here described as emerging through the dynamics in the limbic system. The ego constituting awareness of the self discovers its own nature by observing and analyzing its actions and creations, but cannot claim credit for them. In extreme claims advanced by Nietzsche and Sartre the ego is unconstrained by reality. In more modest terms, because of the circularity of the relation of the self and its awareness, the future actions of the self are shaped in the context of its irrevocable past, its body, its given cultural and physical environment, and its present state of awareness, which is its own creation. The finite brain grapples with the infinity of the world and the uncertainty of the interlocked futures of world and brain, by continually seeking the invariances that will support reliable predictions. Those predictions exist as awareness of future possibilities, without which the self cannot prevail. They are expressed in the feeling of hope: the future need not merely happen; to some extent it can be caused.

13. Conclusion

83 The interactions between microscopic and macroscopic domains lie at the heart of self-organization. How do all those neurons simultaneously get together in a virtual instant, and switch from one harmonious pattern to another in an orderly dance, like the shuttle of lights on the "magic loom" of Sherrington (1940)? The same problem holds for the excitation of atoms in a laser, leading to the emergence of coherent light from the organization of the whole mass; for the coordinated motions of molecules of water and air in a hurricane; for the orchestration of the organelles of caterpillars in metamorphosing to butterflies; and for the inflammatory spread of behavioral fads, rebellions, and revolutions that sweep entire nations. All these kinds of events call for new laws such as those developed in physics by Haken (1983), in chemistry by Prigogine (1980), in biology by Eigen and Schuster (1979), in sociology by Foucault (1976), and in neurobiology by Edelman (1987), which can address new levels of complexity that have heretofore been inaccessible to human comprehension. Perhaps these will serve as the "new laws" called for by Penrose (1994) and Chalmers (1996), but they need not lead to dualism or panpsychism. They can arise as logical extensions from the bases of understanding we already have in these several realms of science, none of which can be fully reduced to the others.

84. Consciousness in the neurodynamic view is a global internal state variable composed of a sequence of momentary states of awareness. Its regulatory role is comparable to that of the operator in a thermostat, that instantiates the difference between the sensed temperature and a set point, and that initiates corrective action by turning a heater on or off. The machine state variable has little history and no capacities for learning or determining its own set point, but the principle is the same: the internal state is a form of energy, an operator, a

predictor of the future, and a carrier of information that is available to the system as a whole. It is a prototype, an evolutionary precursor, not to be confused with awareness, any more than tropism in plants and bacteria is to be confused with intentionality. In humans, the operations and informational contents of the global state variable, which are sensations, images, feelings, thoughts and beliefs, constitute the experience of causation.

85. To deny this comparability and assert that humans are not machines is to miss the point. Two things distinguish humans from all other beings. One is the form and function of the human body, including the brain, which has been given to us by three billion years of biological evolution. The other is the heritage given to us by two million years of cultural evolution. Our mental attributes have been characterized for millennia as the soul or spirit or consciousness that makes us not-machines. The uniqueness of the human condition is not thereby explained, but the concept of circular causality provides a tool for intervention, when something has gone wrong, because the circle can be broken into forward and feedback limbs. Each of them can be explained by linear causality, which tells us where and how to intervene. The only error would be to assign causal agency to the parts of the machine.

14. Summary

86. Science provides knowledge of relations among objects in the world, whereas technology provides tools for intervention into the relations by humans with intent to control the objects. The acausal science of understanding the self distinctively differs from the causal technology of self-control. "Circular causality" in self-organizing systems is a concept that is useful to describe interactions between microscopic neurons in assemblies and the macroscopic emergent state variable that organizes them. In this review intentional action is ascribed to the activities of the subsystems. Awareness (fleeting frames) and consciousness (continual operator) are ascribed to a hemisphere-wide order parameter constituting a global brain state. Linear causal inference is appropriate and essential for planning and interpreting human actions and personal relations, but it can be misleading when it is applied to microscopic-microscopic relations in brains. It is paradoxical to assign linear causality to brains, and thereby cast doubt on the validity of causal agency (free will) in choices in and by humans, just because they are materialized in phase transitions in their brains.

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