

Perception of time and causation through the kinesthesia of intentional action.

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Abstract

Perception is an intentional action through space in time by which the finite brain explores the infinite world. By acting, the brain thrusts its body into the future spacetime of the world while predicting the sensory consequences. Through perceiving its actions and their results, it remembers its predictions, its actions, and their consequences. To perform these operations the brain, through chaotic dynamics, constructs and uses finite perceptual matrices of spacetime and infers causation. Perceived time differs from world time in ways that are determined by the neural mechanisms of intentionality. In particular, perception of the self in action, through the mechanism of preaffference, gives structure and content to the concepts of continuity, contiguity, duration, temporal order, cause, and effect. Perceptual scales are expanded beyond kinesthesia by conversion of time into space, such as by clocks and calendars. Remembered time differs from perceived time in being dependent on awareness, which makes it episodic, fragmentary, and subject to large variations in rates of time lapse in the flow of meanings. The attribution of causal agency to objects and events in the world results from anthropomorphization in accordance with the neural mechanisms of the internal perception of intentional action.

Introduction

What is time? Each of us experiences passage and change, but in a way that is unique, because we see our shared world through eyes and minds that belong to us alone. The 18th century philosopher Immanuel Kant wrote that we can only know our experience of the world and not the world as it is, his "Ding an sich", because, as we would now say, the world is infinitely complex, and we have finite minds. Whatever time may be, it is beyond complete comprehension but not completely beyond comprehension. It comes into our awareness in two ways: as a cycle, and as a line segment.

Circular time has no end. Yet it is finite. We are born without awareness, and we emerge into the theater of consciousness in the rhythm of seconds, hours, days, and years, each following the next and coming full circle with hourly ringing of the bell, nightly prayers, solstices, equinoxes, and one's annual birthday party. We measure the circle of time by the tick marks of actions taken and perceived in repetitive motions: listening to the heart beat, chewing, walking the dog, dancing, clapping, chanting, rowing a boat, watching the sun set, going to sleep, waking to a new day, and to a new year. Cycles are the basis for our ability to predict the future (Freeman, 1995).

The cycles seem endless, yet they are broken, and the thought that breaks them, and sets our awareness on the backward path of nostalgia, is the emergent prediction that each of us will die. Hereby with awareness comes linear time, a line segment, still finite, with a beginning in birth and an ending in death, time the juggernaut that indifferently takes from us all that we have.

Ancient theologians distinguished between worldly time, *chronos*, and eternal time, *kairos*, which was thought to crystallize during portentous events such as miracles and divine births. The secular transmogrification of *kairos* into infinite time came in the scientific revolution of the 17th century, when Descartes invented analytic geometry and used the relation between the real numbers to model time with discrete points on a straight line, marching by rational steps in both directions from the moving moment of now, having no ends, in defiance of God's act of creation and the expected Apocalypse that would consume the world in ice or fire. Once stated, this mathematical form of time serves as a Platonic ideal, but, in itself, it is too simple to be very interesting. Physicists suspect that the time line may actually be a curve, perhaps a circle, that it might flow, not step, that the rates might not be everywhere the same, that the time lines in the universes next door may be skew, and even that time might be a surface instead of a line. However, these cosmological possibilities are not operative on our local scale, where our universal time runs flat out like an arrow. Our finite form of time as we perceive it is continually emerging in our brains as we project our bodies into the future of the world in pursuit of our goals, and intermittently sample it in our memories through awareness.

Commonly we speak of having a sense of timing, of time's passage, as in holding our breath, dancing, speaking, and playing games on shorter time scales, or noting the passing seasons and years on longer scales. These are human scales by direct experience without the microscopes of exceedingly fast electronic and atomic clocks, or the

macroscopes of radioactive decay, DNA patterns, and the astronomical red shift that we use to measure time lapses that are too fast or too slow for direct perception. Clearly our windows of perception in the spectrum of temporal rates of change are closely tied to the inertial characteristics of our bodies in motion. We use our measuring devices to convert time lapses into spatial segments in meters and graphs, in order to hold them for our leisurely perusal. An example is the use of slow motion and time-lapse cinematography to expand the range of time scales, making them accessible for perception. These techniques resemble the use of microscopes and telescopes but with a difference with respect to kinesthesia. We can adapt using a micromanipulator to move microscopic objects, and to the controls of a backhoe, crane, or aircraft that amplifies our muscle power to move macroscopic objects, but our abilities to intentionally move more slowly or rapidly in adaptation to non-human time scales are extremely limited.

The Philosophy of Perception

How do we directly perceive time? This is a philosophical question with a biological answer. The first critical debates about the nature of observation took place in ancient Greece between the followers of Plato and Aristotle. Platonic doctrine held that perception is passive. The world exists as a collection of imperfect copies of ideal forms. The task of the senses is to collect impressions of the forms from examples, and the work of the intellect in the brain is to deduce the ideals. He taught this scheme with the metaphor of the cave. Sunlight passing around the ideal objects cast shadows on the walls, which the senses imprinted onto the body for reasoning by the soul. Aristotelians held that perception is active. The observer acts into the world transitively by probing, cutting and burning, thus to acquire the forms of objects, then intransitively to comprehend the nature of the forms by logic and induction — abstraction and generalization. They held that the actively beating heart is the seat of comprehension, not the motionless brain that serves merely to cool the hot blood.

In modern times Descartes succeeded in mathematizing the Platonic view, but he failed rather badly in his attempt to biologize it. He conceived that the soul, residing in the body like a pilot in a boat, took charge of the machine by controlling the flow of nerve spirits from the brain through the nerves into the muscles, inflating them to make them contract. Physiologists in Italy and the Netherlands quickly showed that muscles do not increase in volume when they shorten in length, and that the ends of cut nerves do not give off bubbles of nerve spirit when they are stimulated. Kant (1781) then revolutionized Platonic doctrine by postulating that the ideal forms are not in the world but in the human mind, and that the world is only indirectly accessed through the impressions that objects make on the senses, from which the intellect constructs representations of the objects. These are all that the observer can know, and not the thing-in-itself.

Cartesian-Kantian doctrine flourishes today in cognitivism, just as the dinosaur is said to survive in birds, because representationalism is at the heart of the logical machines that serve for many people as the instantiation of true intelligence and the early harbingers of the coming termination of the age of biological dominance. In this passive view, time is

represented in our minds by the image of a straight line. The line is dotted with the steps of binary digits and measured by the basic cycle duration of a Central Processing Unit (CPU). The components in bodies and brains that correspond to the CPU are the biological clocks that imperfectly and unreliably give us the time of day or the season of the year, and that express their output in volleys of action potentials, which neurobiologists refer to as "units" when observing them with microelectrodes in awake brains.

Aristotelian doctrine evolved independently and in parallel. It was resurrected from Arabic translations and transformed in the 13th century by St. Thomas Aquinas (1272), whose mission was to make it compatible with the Christian concept of free will. He did this by distinguishing between his conception of the human will versus the Aristotelian concept of intention as biological destiny, which he said humans shared with other animals. Unlike philosophy, which has been dominated by the Platonic passive view, medical science has been dominated by the Aristotelian-Thomist view of active perception, in which the deterministic Cartesian reflex is given its place in the machine, but the maintenance of the machine, according to surgeons, is by healing through first and second intention, and the use of the machine by the pilot is through exercise of the will. The pre-existing word "voluntary" was adapted for this purpose into English by Thomas Hobbes (1651) in the 17th century from the Thomist Latin "volere", and it was firmly placed in the cerebrum by a then eminent neuroanatomist, who left his name on the circle of arteries at the base of the brain, Sir Thomas Willis (1664, 1683). The concept of volition has served as the core explanation of brains in 19th and 20th century textbooks on physiology and neurology, as well as in the doctrines of pragmatism and existentialism, even though people have long since forgotten where it came from. In accordance with this view we perceive time through our experiences of taking action into the space around us (Rosenbaum and Collyer, 1998).

The Evolution of the Perception of Time

Biological intelligence emerged and evolved in the context of brutal chemical warfare: eat or be eaten. Living in a rich organic stew, our ancestors moved in search of molecules that were sloughed off by predators and prey. The ability to move gave animals a competitive advantage over plants, provided they were not throwbacks to sessile forms, but it came at a price. In order to track a sequence of molecules toward a potential source of food or away from a dangerous sink in someone else's maw, an animal had to develop the capacities to navigate in space and time, and to predict the directions, distances and travel times from the present site to significant locations. These neural capacities are apparent in the organization of even the simplest vertebrate forebrain (Herrick, 1948), that of the tiger salamander (Figure 1). Each of the two hemispheres consists of an anterior third devoted to sensation, mostly olfactory, a lateral third devoted to motor functions, and a medial third devoted to the capacities that are required for the spatiotemporal guidance of movements. This medial third is the recognizable forerunner of the hippocampus, which in vertebrates ranging through reptiles and mammals to humans is recognized as being essential to form episodic memories and remember places, that is, for temporal orientation, and for orientation of action in space. This capacity was

designated by O'Keefe and Nadel (1978) as a "cognitive map", after the concept developed by Tolman (1948), but psychologists and roboticists have concluded that this concept is merely a metaphor. They propose that animals (Jacobs 1994) and robots (Hendriks-Jansen 1996) do not literally have maps in their heads, but instead they have the capacity for site-specific regulation of their behavior in spacetime.

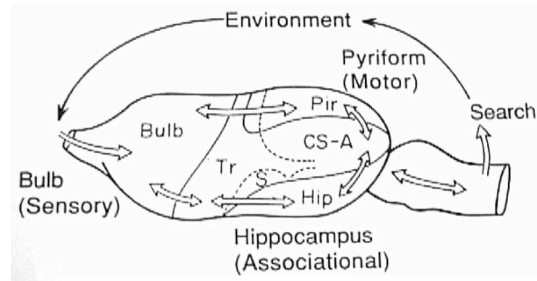


Figure 1. The forebrain is the organizing focus of intentionality in vertebrates. The simplest living example, found in salamanders as sketched here, reveals three essential components: sensory cortex including the olfactory bulb (OB), motor cortex (including the pyriform cortex, PC), and association cortex (labeled here as the hippocampus, H), which are symmetrical in the two hemispheres. The arrows indicate that transmissions between parts are in both directions. The basic architecture of these parts endures through the evolution of brains to mammals and humans as the limbic system. In most vertebrate brains the limbic system is dominated by olfaction, but in human brains it is overgrown in the same way that an ancient town is transformed by its modern suburbs without losing its core role and street plan.

Olfaction is an excellent paradigm for the study of intelligence, because the components are so starkly clear, and mainly because the sense of smell was phylogenetically the first to achieve sophistication, becoming both the final arbiter of success in finding food, and has been the prototype for perception through the other senses. The environment in which it functions is an infinitely complex mix of chemicals. Very few of the mix can lead animals to edible substances, and those few are subject to aging, chemical combinations with other substances, and the vagaries of odor masking. The olfactory receptors in the nose are extremely numerous and exquisitely sensitive in order to facilitate capture of odorant molecules, and they are broadly tuned to an indefinite range of substances, as they must be in order to deal with the incredible richness of the olfactory environment. A single sample taken in a sniff, or its equivalent in animals that do not breathe through their noses, excites a selection of receptors that forms a spatial pattern of neural activity in the arrays of the receptors. That pattern is transmitted by axons into the cerebrum, where it is registered as another spatial pattern of activity by the microscopic neurons that are driven by the afferent volley.

This cortical pattern is the end of sensation, and it presages the beginning of perception. What happens is that the afferent volley of microscopic action potentials from the receptors destabilizes the sensory area of cortex into which it is injected, and the cortex transits from a basal state of expectancy to a new dynamic state (Freeman, 1991, 1995).

This new state leads to the formation of a novel pattern of activity that is generated by the entire sensory area. Whether or not they fire, all of the cortical neurons participate, because patterns require both high and low intensities of activity. This pattern, being macroscopic, has the properties of a mean field that the neurons contribute to and are regulated by. The form of the spatial pattern depends on the intracortical synaptic connections, which have been shaped through learning from past experience. The olfactory area can only generate spatial patterns that result from connections that were modified during experience with a limited number of odorants. Each mean field pattern is a construction of the cortex that is simultaneously transmitted to both the motor area of the cortex and to the hippocampal formation, along with the sensory-driven activity pattern. However, owing to the way in which the cortical pathways are organized, it is the mean field construct that is effectively received by target areas, while the sensory-driven activity pattern that triggered the cortical state transition is deleted (Freeman, 1992).

The reason that the brain works this way is that the environment is far too complex to be defined as a collection of images or representations. Kant was correct in surmising that a human or other animal cannot know the world as it truly is, owing to its infinity of particles of matter and the still greater infinity of the ways they can be assembled. But Kant was wrong in supposing that there are ideal forms of odorant representations in brains, which would have the form of primary or elemental forms from which complex odors are made, as colors are made from red, green and blue. Odor primaries do not exist. Brains can only know what they have learned to hypothesize, including the results of their behavioral testing. These hypotheses are grown and refined through experience (Freeman, 1995).

The Neural Mechanisms of Perception

The sense of time is immediate and unreflective, but the concept of time is abstract and general. It is an example of the way in which humans generalize from particulars. The description I have just given, of how the macroscopic cortical pattern that is triggered by sensory input is effectively transmitted to other parts of the brain, whereas the microscopic sense data are not, constitutes a necessary adaptation of finite biological intelligence to an infinite world. This insight was advanced by Aquinas, who held that the unique and unreproducible forms of matter cannot be known, and that all meaning and knowledge result from acts of the imagination in creating abstractions and generalizations. Recordings of the mean field activity patterns of the olfactory, visual, auditory and somatosensory cortices support this principle (Freeman and Barrie, 1994; Barrie, Freeman and Lenhart, 1996). The same view was held by followers of a medieval school of philosophy, Nominalism, including David Hume (1739), who was led by this fundamental premise to conclude that the abstract idea of causality exists only in minds, not in the material world.

Further concrete evidence for this principle is to be found in the counterintuitive fact that the human brain is in the head. Because it is a 1.5 kilogram mass, it would have had far better protection if placed in the chest, instead of being attached by a slender stalk to the

top of the body. The explanation is that the sensory receptors for events at a distance are located in the head. In particular the retina with their hundred million receptors in the eye is actually an integral part of the brain, and the hundred million chemical receptors in the nose send their axons directly into the brain. The brain immerses itself in the world through these arrays, like the surface of a blob of oil in water. In both cases the immense number of receptors is necessary for the capture of photons and molecules that come from locations far removed from the body. The capture results in the formation of exceedingly complex microscopic spatial patterns of excitation in the arrays of receptors. Their connection pathways to their targets in the brain must be short, because the number of cells is so large, and the axons must be very small, so that their conduction velocities are very low. Therefore, in meeting the requirement for delivery of massive amounts of information with short time delays, the brain must be located very close to the eyes and the nose.

That said, why are the eyes, nose and ears in the head? The answer is obvious, that these sense organs can be directed in space at the front end of the animal, so as to be given optimal orientation toward desired targets during looking, sniffing, and listening. That can be done more flexibly and efficiently when the organs are placed in the head instead of the body. These three senses differ from other senses, such as touch, taste, and muscle sense, in that light wave, sound waves, and chemicals that are carried by convection currents in air and water come from locations far from the body. They provide distant early warnings of the presence and locations of prey and predators, which gives time for the brain to carry out the processes of receiving stimuli, identifying and classifying them, determining their meanings, and devising a suitable plan of action. Within the blanket of spacetime provided around our bodies by the distance receptors, clearly it is the power of prediction that has fueled the intellectual arms race and paced the evolution of biological intelligence.

The Conjoining of Time and Space in Action

The process of action under guidance by odors is complicated by the fact that the odorant molecules carry no information about the spatial locations of their origins. That insight can only be formed in the brain of the pursuer in the following way. A hungry animal captures the scent of food, creates the element of an olfactory percept, and holds it momentarily. It moves, creates a second sample, and determines whether it is stronger or weaker than the one preceding. That difference has no meaning unless the animal retains knowledge of where it was on taking the last sample and where it moved to for taking the next, because those two locations give a direction as to which way to go next, depending on the difference. That knowledge of places depends on combining visual and auditory percepts with those from the somatosensory cortex, which provides proprioceptive input concerning what movements the body has made in the interim between samples. These fragments from the sensory systems are combined into a Gestalt before they are delivered into the hippocampus, where integration takes place over elapsed time and the accumulated experience with spatial locations that is manifested in so-called "place cells" (Wilson and McNaughton, 1993), which are found to fire selectively when animals occupy particular sites in their customary spatial fields of behavioral action. It is the

hippocampus, or more accurately, the collection of neural structures that comprises the hippocampal formation in the medial temporal lobe, which is essential for constructing the spacetime regulatory system that orients search movements through the environment.

Yet deeper meaning lies in spacetime orientation. Prior to each act of observation leading to perception there emerges in this core neural complex a pattern of neural activity that establishes the goal of the act: what it is that the animal seeks, and what it is for. This is the process by which the brain uses the body to engage the environment and assimilate itself in accordance with the sensory results of its own actions. Aquinas described this process by his theory of intentionality. The pattern of neural activity that underlies intentional action is expressed in two ways. One is by actualizing a sequence of motor neuron firings that gives muscle movements to carry the body into goal-directed behaviors. The other is by sending neural messages from the medial temporal cortex to all of the primary sensory areas. These messages, called "corollary discharges" by Roger Sperry (1950), prepare sensory receiving areas for the consequences of the intended actions, and, in particular, sensitize them for the construction of perceptual patterns, should the kinds of expected stimuli turn out to be present. The process underlying purposive action is intention. The predictive process of "preference" (Kay and Freeman, 1998) is observable in the behavioral state of attention, by which a person or other animal holds the several sensory systems in focus in expectation that predicted actions and their forthcoming stimuli will occur as time elapses (von Holst and Mittelstaedt, 1950).

Neither intention nor attention require awareness of the actions or of the stimuli. On the contrary, most of our intentional behaviors unfold habitually, and those most important to us occur in states of intense concentration, when the powers of mind are so focused on the sequence at hand, whether in sport, military action, prayer, love, or creation of a work of art, that awareness is deferred or displaced until the process has reached closure. A good artist holds the ego at bay until it is time for clean-up and critique. When we do become aware of intention, we experience the sequence of the intent to act, the action, the sensory consequences, and the learning that constitutes the up-date of the brain to the current scene. It is in this elementary sequence, constituting an act of observation leading to perception, that causality enters. We experience the action as causing the sensory input. More specifically, we experience the preafferent intent to act, and the ensuing constructions of the sensory cortices in this invariable sequence, as cause and effect. All that we learn and know comes through this process of hypothesis testing, which Merleau-Ponty (1945) described as achieving maximum grip through an intentional arc, and which Jean Piaget (1930) described as "the cycle of action, assimilation, and adaptation" that we learn, as other animals do, in the sensorimotor stage of early development, long before we become adept in the use of language. Thelen and Smith (1994) have extensively developed these insights in the context of dynamic systems theory. Causality is so closely tied to our perception of time, because this aspect of experience takes place through actions in the time and space of ourselves and others like ourselves.

Linear Causality *versus* Circular Causality

The intentional cycle of action-assimilation-adaptation takes us to the center of the web of perceptual being, where we encounter the spider of causality that spins the thread of perceived time (Freeman, 1995). The problem of understanding of causality in the warp and woof of the material and spiritual worlds has bedeviled philosophers for millennia. Ineluctably, causality is bound to the concept of time in both of the two usual senses in which we use the word. On the one hand "to cause" means to bring on an effect or to precipitate some state of affairs by acting as an agent. We refer to usage in the sense of acting as an agent as "linear causality". The criterion by which we justify the application of the term is the strict temporal order between the antecedent cause and the subsequent effect. No effect can precede a cause, but every cause is an effect of a preceding cause. In this way we build linear chains of cause and effect to describe processes we observe in ourselves and in the world. On the other hand "to cause" means to explain or rationalize an observed relationship without invoking an agent. We call this usage "circular causality", and here we allow simultaneity in the bidirectional flow or exchange of influences, which are not merely "very fast", but which transcend time and space and become nonlocal in their conjointness.

Linear causality is very congenial to humans in thinking about the world because it mirrors the intentional arc of Merleau-Ponty (1945): I act (cause), therefore I perceive (effect). An example is Piaget's somatomotor phase of development, in which we learn to experience ourselves as an agent, and we extrapolate that agency not only to other people but to animals and objects in the world. The passive view of perception with its accompanying concept of the reflex is built with causal chains. A stimulus ("*" in Figure 2) carries information to a sensory receptor, causing a cascade of molecular events that transduces it to encode it as a train of action potentials. The train triggers a series of relays through the spinal cord, thalamus and cortex, by which the information is processed into a representation of an object. The image of the object is transmitted to the frontal lobes, where it initiates the processes of identification, classification, and selection of the proper course of action. Then the causal chain of upper and lower motor neurons and muscles effects the action, which becomes the cause of proprioceptive feedback through other causal chains of neurons. By repeated extrapolation the entire life of an animal and its brain can be explained by deterministic causal chains.

Circular causality is foreign to humans to the point of mystification. Yet the active view of perception is drenched in it. The first place that circular causality appears is in the genesis of an intentional state in the core structures of the forebrain ("*" in Figure 3), where the interaction of myriads of neurons grouped into populations leads to a global state transition among them that is expressed in a large-scale pattern of neural activity. The circularity is apparent in the fact that the neurons create the global pattern, while at the same time the pattern constrains and shapes the activity of the individual neurons. There is no way that the actions between the individual neurons can be reduced to linear chains. We see another instance of circular causality in the process by which the volley of action potentials following a stimulus destabilizes a sensory cortex and triggers a state transition leading to the appearance of a macroscopic mean field pattern of activity. These

kinds of transitions have been observed in many physical systems, and have been explained and modeled by physicists in terms of microscopic-macroscopic relationships ever since Ludwig Boltzmann in the 19th century created the science of statistical mechanics from the conjunction of the theory of molecules and classical thermodynamics.

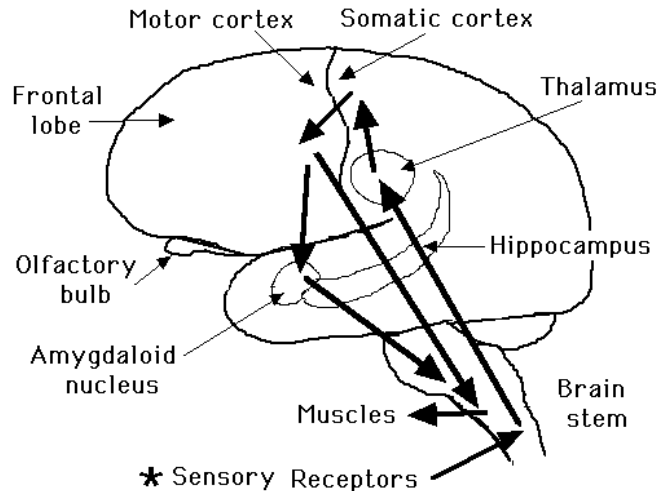


Figure 2. This schematic illustrates the view that materialists and cognitivists share of perception as a passive process. They hold that perception begins when a stimulus gives information that is transduced by sensory receptors into a burst of neural activity that cascades through the brain stem and thalamus into a sensory cortex. The asterix "*" marks where passive perception is started. In the somatic cortex, information processing binds the activity of feature detector neurons into the representation of an object. It is either stored in a local network of neurons, or it is retained and compared with other representations of previous stimuli that were stored and are now retrieved. The winner having the best match is sent by stages to the frontal lobes, where a decision is made to select an appropriate response. The motor cortex sends a command through the brainstem and spinal cord to the muscles. There are several noteworthy side loops. One upward loop is through the reticular formation in the brainstem and thalamus that produces arousal and selective attention. Another is through the cerebellum that fine tunes the behavior. One of the downward loops is through the amygdala, which provides emotional tones from its repertoire of fixed action patterns and its controls on the secretion of emotionally specific neurohormones in the brainstem.

Hermann Haken (1983) developed the Pragmatists view perception as an active process. The asterix "*" marks the site of initiation of active perception. Humans and other animals maintain a stance of attention and expectation, which embodies a hypothesis that is formed by intentional dynamics in the limbic system, and that is transmitted by corollary discharge to all the sensory cortices. The arrival of stimuli confirms or denies the hypothesis. The test of the hypothesis is by state transitions giving amplitude modulation (AM) patterns that converge into the limbic system, in mammals into the entorhinal cortex. A new hypothesis forms, which presages one of a range of possible actions, each with its corollary discharge. The focus of intention is in the limbic system, not in the thalamus or frontal lobe, because the hippocampus provides the neural

machinery for directing intentional action through space and time. Every sensory module must be able to organize its patterns of meaning in space and time. Either it must have its own, or it must share one mechanism after fusion of the multimodal patterns. Evolution's parsimonious solution does not preclude direct exchanges between sensory modules, but it indicates the unique importance of the multisensory convergence into the entorhinal field in synergetics by using the state transition in lasers as his touchstone, and then applying the resulting theory of nonlinear dynamics and chaos to brain function. cortex.

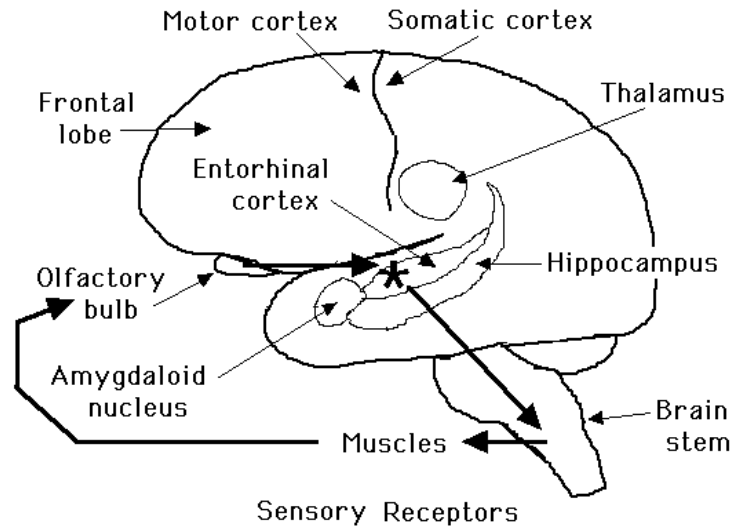


Figure 3. Pragmatists view perception as an active process. The asterisk "*" marks the site of initiation of active perception. Humans and other animals maintain a stance of attention and expectation, which embodies a hypothesis that is formed by intentional dynamics in the limbic system, and that is transmitted by corollary discharge to all the sensory cortices. The arrival of stimuli confirms or denies the hypothesis. The test of the hypothesis is by state transitions giving amplitude modulation (AM) patterns that converge into the limbic system, in mammals into the entorhinal cortex. A new hypothesis forms, which presages one of a range of possible actions, each with its corollary discharge. The focus of intention is in the limbic system, not in the thalamus or frontal lobe, because the hippocampus provides the neural machinery for directing intentional action through space and time. Every sensory module must be able to organize its patterns of meaning in space and time. Either it must have its own, or it must share one mechanism after fusion of the multimodal patterns. Evolution's parsimonious solution does not preclude direct exchanges between sensory modules, but it indicates the unique importance of the multisensory convergence into the entorhinal cortex.

The laser was also used by Cartwright (1989) to exemplify levels of causality. She contrasted simple, direct cause-effect relations that had no significant interactions or second-order perturbations with higher order "capacities" (according to her, closely related to Mill's (1843) "tendencies", but differing by "material abstraction", p. 226), which by virtue of abstraction have an enlarged scope of forward action, but lack the

circular relation between microscopic and macroscopic entities that is essential for explaining lasers — and brains. By further extrapolation, the entire intentional cycle can be seen to exemplify circular causality, because the emergence of a goal thrusts the organism's past into its future and entangles them both into an intelligible whole, the action being an expression of what an animal has learned as much as of what it desires, and the perception being an actualization of patterns that were already created within the sensory areas in cooperation with the core areas.

The entanglement of time and causality becomes obvious when we take a closer look at how neurobiologists derive proof of linear causal chains by observing and measuring stimulus-response (S-R) relationships in an animal. The demonstration of the invariance of the cause-effect relation must be based on repeated trials (Figure 4). On each trial the observers must segment the infinite time line of reality and reset observer time to zero. They assume that the conditions of the experiment remain constant across trials, or they make corrections for fatigue, satiety, boredom, distractions, and cumulative learning. They collect multiple S-R pairs and assemble them by aligning the zero points in a spatial display. The double dot indicates a point in real time, which disappears irretrievably from observer time.

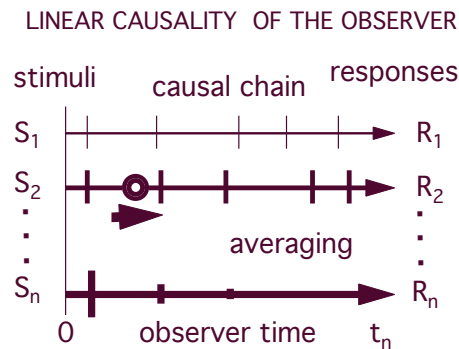


Figure 4. Linear causality is the view that events are connected by causal chains. The observer must create an artificial time, here labeled "observer time, t_n ", to summarize the average over real time in which the individual events, S_1 & R_1 , etc., were collected. The encircled dot represents an instant in real time. The weaknesses of this view lie in the requirement for constructing explanations to assign points in time to the beginning and the end of each chain, as well as to intervening events in the chain in strict order, and to make observations repeatedly 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, leading 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 that is acting to produce an effect, and that then becomes the next cause.

Some form of generalization is required over the pairs. In the example shown in Fig. 4, observers do it by time ensemble averaging. This leads to a problem, because the response does not come with a fixed latency, and sometimes it doesn't come at all. Observers who are working in the paradigm of active perception will expect this, because they see the response as self-organized, merely triggered some time after the stimulus in each trial and occurring at the pleasure of the animal, but observers who are working in the paradigm of passive perception expect that each stimulus will initiate a causal chain of events in each trial, such as those indicated by the tic marks on each time segment in Figure 4. These serial events do not occur reliably at the same latencies from the zero point, which typically is selected by the observers independently of what the animal under observation is doing. Events that are early in the chain just after the time of onset and close to stimulus arrival tend to have smaller variances in latency, so they are retained under averaging. Later events with more widely varying latencies tend to be lost. The observers attribute the variance in latency to chance or to noise, which is their rationale for using averaging.

The outcome of the procedure is to enhance the features of the response that depend on the stimulus and to diminish the contributions made by the animal. That reinforces the utility of the passive paradigm in the minds of the observers, but at the cost of an anomaly. Brains have no neural mechanisms for storing and averaging single trials in the way that observers do. On the contrary, the function of sensory cortex, for reasons discussed, is to construct a mean field pattern and remove the stimulus-driven activity as trash. The observers who use averaging thereby remove the self-organized constructs formed on each trial, and what they retain for analysis is brain refuse. We might call this group of observers neuroarcheologists in recognition of the fact that many valuable insights about the life styles of our remote ancestors have come from archeological analysis of middens. The elements of circular causality are shown in Figure 5. The encircled dot shows a point moving counterclockwise with real time on a trajectory idealized as a circle, in order to indicate that a perceptual event exists irreducibly as a state through a period of inner time, which we can idealize as a point in real time. External stimuli from the world impinge on this state. So also do internal stimuli that emerge through the self-organizing dynamics within the core of the brain. Most stimuli are ineffective, but occasionally one succeeds as a "hit" on the brain state, and a response occurs. The impact results in a nonlinear state transition, which is followed by a change in brain structure, that we identify with learning, and that begins a new orbit. 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. The circular trajectories in inner time fuse the past and the future into an extended present that constitutes a state that is entered and left by state transitions.

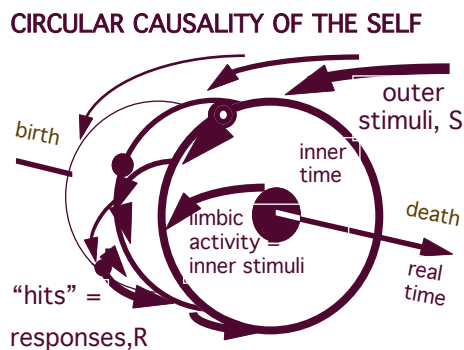


Figure 5. Circular causality expresses the interrelations between levels in the hierarchy of brain dynamics: a top-down macroscopic state simultaneously influences and constrains the microscopic particles that, bottom-up, create and sustain the macroscopic state. The state exists over a span of inner time in the system that we tend to collapse to a point in external time. Events in real time are marked by discrete state transitions in the state of the system. A "hit" denotes the impact of an external stimulus onto a cortex prepared by prefference, so that a state transition ensues. Without such preparation, nothing happens, and that is the case for the great preponderance of sensory inputs. I postulate that internal stimuli arising by self organizing processes in the limbic system can operate in place of external stimuli, in the process of imagination. The encircled dot represents the mythical moment of "now". The concept of circular causality is widely used in the social and physical sciences. In an example used by Haken (1983), excited atoms in a laser cause coherent light emission, and the light imposes order on the atoms. In circular causality, multiple scales of time and space are required for the different levels of brain hierarchies, and the notion of an agent or "agency" does not enter.

Keeping Ourselves on Time

Since perception of time is through our awareness of the intentional process, it can be accessed either in respect to the onset of an external stimulus or of an internal preafferent message presaging a goal-directed action. However, as shown in Figure 5, there are two time lines, one linear signifying a segment of real time, the other circular showing perceived time. Awareness of percepts is not simultaneous with the onset of the stimulus, nor with the state transition that constitutes the initial planning of an act. A neural mechanism exists that keeps perceived time sufficiently close to the flow of events in real time that actions are effective even in the course of exceedingly rapid external flows. That mechanism was revealed by experiments conducted by neurophysiologist Benjamin Libet (1994) in collaboration with neurosurgeons to measure the time lapse between stimulus and awareness.

For diagnostic purposes surgeons placed electrodes in the brains of patients to guide treatment of intractable epilepsy. Some patients volunteered to partake in a fundamental test, in which they remained awake and reported the effects of direct electrical stimulation of their brains after surgical exposure under local anesthesia. On some trials

the surgeons stimulated a nerve in the patients' left hand, which evoked an electrical response in the right sensory cortex almost instantly by a very fast pathway to the sensory cortex. The patients reported feeling the stimulus half a second later. On other trials the surgeons gave an electrical stimulus directly to the exposed left sensory cortex, which bypassed the fast pathway from the right hand, and which caused immediate onset of a sensory cortical response. In this case also about a half a second elapsed before the patients reported perceiving the stimulus, despite the very short time delay in the onset of the evoked potentials in the cortex in both experiments.

Two aspects of Libet's experiment are especially important for interpretation. First, the stimulus given to the left hand could be felt no matter how brief it was, but the stimulus given directly to the left cortex had to be a pulse train that lasted at least a quarter to a half a second to achieve what Libet called "neuronal adequacy" for awareness. Briefer duration required higher stimulus intensity. Second, the awareness of the direct electrical stimulus to the left cortex was assigned by the patients to the end of the pulse train, the time for "neuronal adequacy", but awareness of the stimulus given to the left hand relayed to the right cortex was back-dated to its time of occurrence. Back-dating keeps brain function in synchrony with the flow of real time, despite the obligatory delay in the formation of a percept. Anyone who plays on a sports team or in an orchestra knows the necessity of keeping rapid sequences of behavior in harmony with the group, at rates of change too fast to allow perceptual frames in succession, yet requiring integration into the shared time sequences of the unfolding events.

Libet showed that the neural basis for the back dating is provided by one of the two somatosensory channels, the lemniscal system. Its ascending axons are fast and unbranched, and the system reports to the cortex in under 30 milliseconds exactly where and when a stimulus hits the skin. Libet found that patients could back date if he stimulated in the thalamus and included that pathway, but otherwise could not. In contrast, axons in the spinothalamic system are slow and branch extensively into the reticular formation, and the cumulative after discharges they induce give the basis for perceiving the stimulus half a second later, but perception of the time and place of onset is based on lemniscal input. Experimental psychologists commonly use a *double threshold* technique to detect events in noisy time series. They use a high threshold to determine that an event with gradual onset has occurred, and a low threshold to back date the time at which it began. In constructing a mechanical model of learning Walter (1963) used two electronic circuits, one with a step output to report "that an event happened", the other with a pulse output to report "when it happened". When physiologists in other experiments cut all spinal tracts in rats, except that for the lemniscal system, and tested its function, the rats ignored all stimuli below the level of the cut (Melzack and Wall 1983), leaving the question: What does the system do? Libet's work gives an answer. It is the lemniscal system that coordinates perceived time with real time.

Although Libet's experiment has been severely criticized for failure to develop an accurate measure of inner awareness, the facts remain that awareness is a more complex process than the induced state transitions in sensory cortices, and that it requires more time. Libet and several other neurobiological groups have also deduced from

measurements of brain activity in human volunteers that a comparable delay exists in the onset of awareness of a self-paced action, such as when the scientists ask an experimental subject to press a switch briefly, at his or her own inclination, now and then over the course of an hour. . In this experiment a slow change in electric potential is recorded with scalp electrodes between the top of the head and the base at the earlobes. This slow increase is called the readiness potential. It starts about a second before each self-paced movement. The potential change is so small that it can be detected only by averaging over numerous trials, but it shows that neural activity involved in the planning and organization of the movement precedes the awareness of an intention to act. The length of time by which the awareness follows the onset of the readiness potential is comparable to the delay in the awareness of a stimulus onset. That is, when the subjects are asked to report the time of onset of their awareness of their decision to initiate pressing the switch, the timing of their responses indicates that their awareness follows the onset of the readiness potential by a quarter to half a second.

The results show that perception and action both run in perceived time quite smoothly without awareness, and that intention surfaces intermittently into awareness for a query or an update, filling in the gaps of awareness by remembering. This appears to be why remembered time is so much more fallible than the perceived time that underlies awareness, which performs continuously and effortlessly in support of attempts to achieve desired goals. Perceived time varies in rate with the degree of urgency of movements, from glacially slow in attitudes of repose to lightning fast in moments of danger, and the residues in episodic memory reflect these undulations in perceived time's pace. At the pathological extremes, patients in the manic phase of bipolar disorder, whose rate of time is accelerated, flit about like butterflies, and for patients with the cogwheel rigidity and paralysis from advanced Parkinson's disease, perceptual time slows to a crawl, and remembered time stops in deep freeze (Sacks, 1974). Despite tours de force such as the novels of Marcel Proust and James Joyce, recall is not a reliable way to study finite time, owing to the sparseness by which the intentional process is sampled and monitored in awareness.

Conclusion

The analysis of neurophysiological data indicates that the perception of time and the perception of causality have their origins in the same intentional cycle that produces goal-directed actions that are accompanied by preference, attention, and learning from the perceived consequences of acting. Therefore the perceptions of time and causality are inextricably linked. The concepts to which they give rise have similar but somewhat different fates. Time has been abstracted by mathematicians to give linear form to the intuition that it might never have a beginning or an end, and thereby it is inferred to be a physical reality. Causality has traditionally been assigned to objects and other animals in the physical world, but primarily it has always been a social reality. It is the bedrock for the assignment of credit and blame, for reward and punishment, and for attribution of legal and moral responsibility to the individual perpetrators of deeds and misdeeds. Time has also come into the social realm by use of clocks, as the means for coordinating the actions of large numbers of semi-autonomous workers in offices, factories, and systems

for communication and transportation. Causality currently is applied in the physical realm, where it justifies the search for invariant relations in controlled experiments, and for applications of scientific knowledge to the technological solution of human problems. Both concepts are finite constructs from human minds. I believe that time does exist in the material world, but causality does not. Why should time and cause differ? Time is the measure of motion, and cause is the measure of intent. All living forms have motion, but only humans have intentionality in the fullest sense of the concept.

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References

- Aquinas, St. Thomas (1272/1952) *The Summa Theologica*. Translated by Fathers of the English Dominican Province. Revised by Daniel J Sullivan. Published by William Benton as Volume 19, Great Books Series. Chicago: Encyclopedia Britannica, Inc.
- Barrie JM, Freeman WJ, Lenhart M (1996) Modulation by discriminative training of spatial patterns of gamma EEG amplitude and phase in neocortex of rabbits. *Journal of Neurophysiology* 76: 520-539.
- Cartwright N (1989) *Nature's Capacities and their Measurement*. Oxford UK: Clarendon Press.
- Davidson D (1980) *Actions, reasons, and causes*. In: *Essays on Actions & Events*. Oxford UK: Clarendon Press.
- Freeman WJ (1975) *Mass Action in the Nervous System*. New York: Academic Press.
- Freeman WJ (1991) The physiology of perception. *Scientific American* 264: 78-85.
- Freeman, WJ (1992) Tutorial in neurobiology: From single neurons to brain chaos. *International Journal of Bifurcation and Chaos* 2: 451-482.
- Freeman WJ (1995) *Societies of Brains. A Study in the Neuroscience of Love and Hate*. Mahwah NJ: Lawrence Erlbaum Associates.
- Freeman WJ (1999) *Consciousness, intentionality, and causality*. *Journal of Consciousness Studies* (in press).
- Freeman WJ, Barrie JM (1994) Chaotic oscillations and the genesis of meaning in cerebral cortex. In: Buzsaki G, Llinás R, Singer W, Berthoz A, Christen Y (eds.) *Temporal Coding in the Brain*. Berlin, Springer-Verlag, pp 13-37.
- Haken H (1983) *Synergetics: An Introduction*. Berlin: Springer.
- Hendriks-Jansen H (1996) *Catching Ourselves in the Act: Situated Activity, Interactive Emergence, Evolution, and Human Thought*. Cambridge, MA: MIT Press.
- Herrick CJ (1948) *The Brain of the Tiger Salamander*. Chicago IL: University of Chicago Press.

- Hobbes T (1651/1904) *Leviathan; or, The Matter, Forme and Power of Commonwealth, Ecclesiasticall and Civill*. Waller AR (ed.) Cambridge UK: Cambridge University Press.
- Hume D (1739) *Treatise on Human Nature*. London: J Noon.
- Jacobs LF (1994) Natural space-use patterns and hippocampal size in kangaroo rats. *Brain, Behavior and Evolution* 44:125-132.
- Kant I (1781/1974) *Kritik der reinen Vernunft* (von Weischedel W, ed.). Frankfurt am Main: Suhrkamp Verlag.
- Kay LM, Freeman WJ (1998) Bidirectional processing in the olfactory-limbic axis during olfactory behavior. *Behavioral Neuroscience* 112: 541-553.
- Libet B (1994) *Neurophysiology of Consciousness: Selected Papers and New Essays*. Boston MA: Birkhauser.
- Merleau-Ponty M (1945/1962) *Phenomenology of Perception*. (C Smith, Trans.). New York: Humanities Press.
- Mill JS (1843/1965) *Of Liberty and Necessity, Ch. II, Book VI. A System of Logic*. London UK: Longmans, Green, 18th ed.
- O'Keefe J & Nadel L (1978) *The Hippocampus as a Cognitive Map*. Oxford UK: Clarendon Press.
- Piaget J (1930) *The Child's Conception of Physical Causality*. New York: Harcourt, Brace.
- Proust M (1919/1927) *A la Recherche du Temps Perdu*. Paris: Gallimard.
- Rosenbaum DA, Collyer CE (1998) *Timing of Behavior. Neural, Psychological, and Computational Perspectives*. Cambridge MA: MIT Press.
- Sacks OW (1974) *Awakenings*. New York: Doubleday.
- Sperry RW (1950) Neural basis of the spontaneous optokinetic response. *Journal of Comparative Physiology* 43: 482-489.
- Thelen E, Smith LB (1994) *A Dynamic Systems Approach to the Development of Cognition and Action*. Cambridge MA: MIT Press.
- Tolman EC (1948) Cognitive maps in rats and men. *Psychological Review* 55: 189-208.
- von Holst E & Mittelstädt H (1950) Das Reafferenzprinzip. *Wechselwirkung zwischen Zentralnervensystem und Peripherie. Naturwissenschaften* 37: 464-476.
- Willis T (1664/1964) *The Anatomy of the Brain and Nerves (Cerebri Anatome)*. Feindel W (ed.) Montreal, Canada: McGill University Press.
- Willis T (1683/1971) Two discourses concerning the soul of brutes, which is that of the vital and sensitive of man. Diamond S. (introduction). Gainesville FL: Scholars' Facsimilies & Reprints
- Wilson MA & McNaughton BL (1993) Dynamics of the hippocampal ensemble code for space. *Science* 261: 1055-1058.