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From the Percept to the Mind

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The Sensory Order. In *The Collected Works of F. A. Hayek,* Volume 14 (edited by Viktor J. Vanberg). Chicago: University of Chicago Press, 2017, 316 pages, $59.40 hardcover.

Hayek's Methodology

The Sensory Order is the best known and distinctive of Hayek's books on theoretical psychology. His book has the undisputable merit of offering a truly prescient account of the role of the nervous system in cognitive functions, notably perception. Now, more than six decades after its publication, this account remains the most plausible exposition of the principles of functional architecture of the cerebral cortex in sensory perception.

Hayek allegedly used to say, "Without a theory the facts are silent." *The Sensory Order* is his theory of the mind, and the facts of modern neuroscience speak eloquently for it. Yet, even incipient theories are based on facts, and around 1920, when Hayek wrote his first — unpublished — essay on perception, the established facts of the relevant brain physiology were limited; they were still limited in 1950, when that essay, together with other drafts and essays, merged into *The Sensory Order.* It may be for that reason that, by his own admission, this book was difficult to write, and is probably the most difficult to read of his entire literary legacy.

Nonetheless, behind the difficult prose and the peculiar neologisms of necessity, Hayek in this book laid out the groundwork for cognitive neuroscience at large, even though his focus was on sensory perception. If only few neuroscientists recognize it, it is because most of the others are beset by the very same prejudices that he began assailing as a student in Vienna.

The most pervasive and enslaving prejudice in cognitive neuroscience today is — as it was then — the faithful belief in reductionism: the search for the ultimate causes and essential elements in physical phenomena. Such phenomena, of course, include the human mind, which is by definition the prime and to us most proximate phenomenon of nature. Deterministic reductionism is the golden rule of all the physical sciences, yet it fails miserably when it comes to the mind and its substrate in the brain.

Hayek began his quest for perception by disputing Mach's radical reductionist proposition: the existence of the elementary "atom" of sensation, an irreducible pure sensation

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on which all other sensations and percepts of the external world would be built. He argued that there was no need for that elementary entity. Instead, he argued that all sensory percepts, however simple, were made of *relations* between co-occurring sensory impulses arriving in the brain in the course of life experience. The "sensory history" of percepts was not limited to individual experience but, in the case of the most elementary sensations, it extended to evolutionary experience, in other words, to the history of the species (the genetic, innate, structure of sensory systems, which I term "phyletic memory"). Inasmuch as he attributed sensory perceptions and mental phenomena to relations between simpler elements of sensation, Hayek was a precursor of modern connectionism.

For him, the system of connections resulting from the sensing of the world becomes the infrastructure of the sensory order, embodied by a corresponding order of connections in the brain. That embodied relational system becomes the neural and mental apparatus for perception, which becomes the classification of objects in the external world performed by that "knowing" cerebral apparatus. A percept is the act of interpreting an object by the sensory order pre-established in the brain and, at the same time, the act of incorporating that object into that order, whereby the latter is refined and expanded.

The connective system that represents the sensory order is isomorphic to the phenomenal order, such that changes in one correspond to similar changes in the other (similar, that is, in quality or relative magnitude). This isomorphism of two relational orders is conceptually germane to the principles of Gestalt psychology, which is one of the intellectual roots of *The Sensory Order*. Note, however, that Hayek takes pains to differentiate his isomorphism from that of Gestalt. He emphasizes that the topological correspondence between sensory order and phenomenal order does not have any of the spatial and innate attributes of Gestalt.

In conclusion, the cerebral connective system that constitutes Hayek's sensory order has two complementary functions that operate simultaneously in tandem: one receptive and the other projective. On the one hand, the system makes new memory out of new experience; on the other, the system perceives ("classifies") the world, projecting memory onto it and thereby updating memory. In this manner, Helmholtz's dictum becomes both understandable and compelling: not only do we remember what we perceive, but also perceive what we remember (Helmholtz, 1925).

In Volume 14 of Hayek's Collected Works, *The Sensory Order*, which is the focus of this review, is preceded by an excellent introduction from the volume's editor, Viktor J. Vanberg. Its central theme is the thorough scholarly review of the intellectual history and background of *The Sensory Order*. I was pleasantly surprised to find in it excerpts of my personal correspondence with Hayek, from the 1970's. That correspondence dealt mainly with the physiological substrate and mechanisms postulated in *The Sensory Order.* Because our knowledge of those matters has advanced considerably since then, I devote to them the remainder of this review.

The Cognitive Network (Cognit)

To say that the cerebral cortex contains and utilizes an immense network of interconnected neurons is to declare a truism. What is not a truism, and well supported by recent neuroscience, is that that immense network is exquisitely plastic and susceptible to changes by sensory and motor experiences. As a result of those experiences, there is enormous structural and functional specialization within the global cortical network. That specialization derives largely from the fact that the connections between the neurons of the network, that is, their synapses, are continuously and differentially modulated by life experiences.

That modulation, first proposed by Cajal (1923/1966), results from the temporal coincidence and association of nerve impulses of different origin, as Hebb (1957) and Hayek later postulated in detail. We know that, by strengthening certain synapses within the cortical network, different experiences "carve out" the specialized networks that represent those experiences as memories. These specialized "sub-networks" constitute what I call *cognits,* the basic units of memory and knowledge. They are also the units of perception, thus representing in the cerebral cortex what Hayek called the "classes" of percepts, as well as his "maps" and "models." Indeed, cognits are the basic functional units with which all major cognitive functions operate: attention, perception, memory, intelligence, and language (Fuster, 2003).

Cognits emerge from synaptic association of simultaneous or near simultaneous stimuli. Also by association, cognits are activated and brought into consciousness and behavior. The strength and resilience of a cognit, as well as its accessibility to perception or recall, depend on the strength and resilience of its synapses. New cognits are made of associations, not only between novel co-occurring stimuli, but also between such stimuli and old cognits somehow associated with them in the past. In this manner, novel experiences update and expand old memories.

Because cognits share in common many cognitive features (i.e., the neuronal groups that represent those features), a neuron practically anywhere in associative cortex can be part of many percepts, memories, or items of knowledge. As a result, the overarching associative cortical network is actually made of a complex, almost infinite, array of profusely *overlapping* and *interactive* cognitive networks or cognits. Critically, those networks are hierarchically organized over the surface of the cortex.

Hayek was envisioning that kind of hierarchical organization when he spoke about "classes" and "classes-of-classes" of percepts, the former nested within the latter. It is only now, however, in the light of current neuroscience that the classes of perception can be readily identified as cognitive networks or cognits. Nesting and hierarchy are essential properties of the cortical organization of such networks, as they are of Hayek's sensory order.

Hierarchical Organization of Cognits in the Cerebral Cortex

Hayek's hierarchical order of perception and perceptual memory, with the most general categories on top and the simplest and most concrete at the bottom, reflects a corresponding hierarchy of cognitive networks in posterior cortex, the cortex behind the Rolandic fissure. For each sensory modality (vision, audition, etc.), a succession of interconnected cortical areas, extending over the cortical surface from primary sensory cortex to higher association cortex, houses a hierarchy of progressively wider and more complex cognitive networks. These networks represent progressively wider and more complex perceptual categories and memories. Some of the higher networks connect to networks of different modality, thus together representing cross-modal percepts (e.g., visual–auditory). Further, some networks are "heterarchical," in that they associate neuronal groups or networks of different level.

At the highest levels of the perceptual hierarchies of posterior cortex, the cognitive networks associate sensory features of diverse origin with established conceptual cognits. This is the case, for example, in the superior parietal cortex (which includes Wernicke's area), where the sounds and graphics of words merge into high level cognits of semantic memory that are essential for the understanding and production of language.

The reader of *The Sensory Order* familiar with cortical neuropsychology will immediately recognize in that hierarchical organization of posterior cortex the sensory order of Hayek's classes of perception. Many questions, however, remain unanswered about how that perceptual hierarchy is formed in our brain in the course of our lives. The evidence from basic

neurobiology and cortical physiology points to the critical role of *self-organization* by usage in the formation of cognits, in fulfillment of Hebbian–Hayekian synaptic principles.

Accordingly, when we have a new experience, the stimuli that it elicits "resonate" with similar — cognitive and emotional — stimuli that formed prior networks in our perceptual hierarchy. That association by similarity evokes the perceptual memory of those networks and, with it, two things happen: (a) a new perceptual cognit is, in Hayek's terms, classified and synaptically incorporated in the same hierarchical level as similar prior cognits, and (b) the new cognit expands and updates the old ones making them more categorical and/or discriminant.

The development of the perceptual hierarchies in posterior cortex, as well as the formation in them of acquired cognits and memories, follows a distinct anatomical trend. From area to area, that trend conforms to three neurobiological gradients that depart from primary cortex and progress toward and into cortex of association: (1) phylogenetic development (evolution) as indicated by comparative anatomy, (2) the direction of major fiber connections for sensory transmission into association cortex, and (3) myelogenesis, the development around and after birth of mylinated, fast-conducting, fibers. Therefore, individual perceptual memories are formed on a base of primary sensory cortex (phyletic memory) and find their niche along their hierarchy in cortex of association.

In parallel with the perceptual hierarchy that accommodates the sensory order, there is in the cortex of the frontal lobe a hierarchy of areas that accommodates the experience of action. Hayek is fully aware of the need for an executive hierarchy to complement the sensory hierarchical order in behavior. He even postulates similarities in the organization of the two hierarchies, as he sees them sharing the essential features of nesting and classifying. Thus, referring to a hypothetical motor order and its correspondence to the sensory order, he writes (p. 217): "At the higher centers the connections will thus increasingly exist, not between particular stimuli and particular responses, but between classes of stimuli and classes of responses, and between classes of classes of stimuli and classes of classes of responses, etc."

Without apparent awareness of the frontal motor hierarchy (first outlined by J.H. Jackson, 1958) and to account for a motor order, Hayek attempts to extend the sensory order by incorporating in it the proprioceptive sensory inputs that result from muscular movement. The attempt is incomplete, however, because it fails to take into account the extensive gamut of human action, notably to include, at higher levels, concepts and plans of action. Recent neurophysiology and functional brain imaging complete the account. Further, they show the coordination of sensory and motor categories in the intricate dynamics of the perception–action cycle.

The Perception–Action Cycle

In all purposive behavior and language, there is a continuous dynamic interplay between the posterior (sensory) and frontal (executive) cortices and the environment; that interplay goes on until the objective has been reached. The interplay constitutes the perception–action cycle, namely, the circular cybernetic flow of information between the organism and the environment that governs all sequences of goal-directed actions. At the beginning or in the course of any such sequence, sensory environmental stimuli are processed bottom–up through the posterior cortical hierarchy. The outcome of that sensory processing is communicated to the action hierarchy in frontal cortex, which mediates the execution of the subsequent and consequent act. That act will generate new sensory stimuli, which will inform the next act, and so on until the sequence reaches its goal.

Hayek suggests the infrastructure of the perception–action cycle in the form of interactions, at several levels, between the two hierarchies, sensory and executive. Further, he

suggests that what happens in the brain at low levels, with simple movements responding reflexively to simple stimuli, is paradigmatic of general mechanisms at all levels. He would not go beyond that, because the neural dynamics of the cycle were still unknown when he wrote *The Sensory Order*. Even at lower levels of the nervous system, however, he would mention the necessity for an important feature of the cycle: feedback. He writes, . . . "it will be necessary to consider with some care the role . . . [that] peripheral movements can play in the structure of nervous action. The first point which requires emphasis is that peripheral events, in order to influence further central nervous processes, must be reported back to the centers in which these processes take place" (p. 213).

By feed-forward and feedback in its neural links, the perception–action cycle engages the posterior and frontal cortices in the reciprocal interaction between them and the environment. We know that in the brain that interaction is largely mediated by long fiber connections (superior longitudinal fasciculus) between the two cortical moieties, posterior and anterior, of both cerebral hemispheres.

A prime example of the workings of the perception–action cycle at the highest levels of associative cortex is the dialogue between two speakers. Within the posterior cortex of one of the speakers, a statement by the other will be processed for meaning and logic. Resulting from this processing will be input to the listener's frontal cortex, which will process his verbal response and prepare his cortex for the anticipated response of the other speaker. Such a cycle will continue in each interlocutor until closure is reached, with agreement — or irreconcilable dissent. The most cursory analysis will lead to the conclusion that the dialogue results from two interlocked perception–action cycles, each circulating through the brain of each interlocutor.

Prediction and Preadaptation: The Prefrontal Cortex

Contributing to the formation of the sensory order, Hayek writes, are the stimuli from the *internal milieu*, the internal environment of the organism. At the lowest, most basic, biological level, these stimuli activate reflexes that regulate and maintain the stability of that environment in terms of hormonal balances, temperature, visceral functions, metabolism, etc. Those reflexes are innate and may therefore be considered part of the "phyletic memory" of the organism. They can be, however, modified, conditioned, assisted or overridden by influences from higher levels, whether from the cortical sensory order or from the executive — frontal — order.

From the structures that regulate the internal milieu (hypothalamus and limbic system), neural impulses will flow onto the executive structures of the frontal lobe, for these to integrate behavioral actions anticipating changes in that milieu and preparing the organism for them. If needed, they will correct those changes with behavioral action *before* they occur. That proactive preparation for, and preemptive correction of, expected changes of the internal milieu fall in the category of what can be called pre-adaptive action, an important role of the frontal cortex. An example of such actions would be the timely visit to a restaurant, or to a doctor for a medical checkup.

Preadaptive action requires prediction and the planning for future objectives. For this reason the cortex of the frontal lobe has been considered a "teleological" structure, its function "determined by the future." To avoid a scientific paradox (the temporal inversion of cause and effect), it would be more appropriate to use Monod's term *teleonomic* — with its biological connotations — as the qualifier for what Hayek calls *biogenic needs and drives*. From the point of view of "neuroeconomics,"the cortex of the frontal lobe appears, indeed, critically involved in the pursuit of biological values and rewards, however distant in the future.

At higher levels of the perception–action cycle, the prediction and preadaptation will become what Hayek considers conscious *purpose*. Now we know that the executive functions at the service of prediction and adaptation constitute the physiological purview of the prefrontal cortex, the highest level of the hierarchy of executive cognits.

The prefrontal cortex, the associative cortex of the frontal lobe, has the general function of temporally organizing goal-directed behavior and language. That general function is assisted by the following executive control functions: *planning, perceptual attention, executive attention (set), working memory, and decision-making*. All these five functions, which the prefrontal cortex performs in coordination with other brain structures, are prospective, that is, *oriented to the future* (Fuster, 2013). All five assist the brain in mediating cross-temporal contingencies in the perception–action cycle.

Among all structures of the brain, the prefrontal cortex is the last to develop, in evolution as in the development of the human individual. In phylogeny as in ontogeny, it is the part of the cerebral cortex to undergo the greatest development, not only in volume but also, most important for cognition, in connectivity. To reach their maximum in the prefrontal cortex of the mature human, fiber connections grow exponentially after birth. That degree of connective development can only be understood by considering the enormous expansion of the possibilities of imagined and actual actions that the development of the prefrontal cortex carries with it. It may be said that, by its expanding connectivity, the prefrontal cortex literally opens the organism to its future.

Because the prefrontal cortex is critical for the organization of future action, the patient with an extensive lesion of this cortex is notoriously incapable of formulating and executing plans of goal-directed behavior. The functional imaging of the brain shows that the mere *thinking* of a plan of movements activates the same frontal networks that are activated by the execution of the plan. Facts of this kind not only attest to the insight of Hayek's theory, but also allow us to respectfully question the last sentence of his *The Sensory Order* (p. 304), a sentence clearly written in a philosophical vein: "Even though we may know that mental events of the kind which we experience can be produced by the same forces which operate in the rest of nature, we shall never be able to say which are the particular physical events which 'correspond' to a particular mental event." That may be true for events in the outer world but not for events inside the brain.

References

Cajal, S. R. (1966). *Recollections of my life* [E. H. Craigie and J. Cano, Trans.]. Cambridge, Massachusetts: MIT Press. (originally published 1923)

Fuster, J. M. (2003). *Cortex and mind: Unifying cognition.* New York: Oxford University Press.

Fuster, J. M. (2013). *The neuroscience of freedom and creativity: Our predictive brain.* Cambridge: Cambridge University Press.

Hebb, D. O. (1957). *The organization of behavior.* New York: John Wiley & Sons, Inc.

Helmholtz, H. v. (1925). *Helmholtz's treatise on physiological optics* [J.P.C. Southall, Trans.]. Menasha, Wisconsin: The Optical Society of America.

Jackson, J. H. (1958). *Selected writings.* New York: Basic Books.

Monod, J. (1971). *Chance and necessity*. New York: Knopf.