1. A Theory of the Brain

Marr’s initial work in neuroscience combined high-level theoretical speculation with meticulous synthesis of the anatomical data available at the time. The question he chose to address is the nec plus ultra of neuroscience: what is it that the brain does? Marr proposed a definite answer to this question for each of three major brain structures: archicortex (the phylogenetically older part of the cerebral cortex), cerebellum, and neocortex. The three answers complement each other, rallying around the idea that the brain’s central function is statistical pattern recognition and association, carried out in a very high-dimensional space of ‘elemental’ features. The basic building block of all three theories is a codon, or a subset of features, with which there may be associated a cell, wired so as to fire in the presence of that particular codon.

In the first paper, Marr proposed that the cerebellum’s task is to learn the motor skills involved in performing actions and maintaining posture (Marr 1969). The Purkinje cells in the cerebellar cortex, presumably implementing the codon representation, associate (through synaptic modification) a particular action with the context in which it is performed. Subsequently, the context alone causes the Purkinje cell to fire, which in turn precipitates the next elemental movement. Thirty years later, a significant proportion of researchers working on the cerebellum seem to consider this model as ‘generally correct’—a striking exception in a field where the nihil nisi bono maxim is not known to be observed.

The next paper (Marr 1970) extended the codon theory to encompass a more general kind of statistical concept learning, which he assessed as ‘capable of serving many of the aspects of the brain’s function’ (the vagueness of this aspect of the theory would lead him soon to abandon this approach, which, as he realized all along, was ‘once removed from the description of any task the cerebrum might perform’). How can a mere handful of techniques for organizing information (such as the codon representation) support a general theory of the brain function? Marr’s views in this matter are profoundly realist, and are based on a postulate of ‘the prevalence in the world of a particular kind of statistical redundancy, which is characterized by a “Fundamental Hypothesis,” stating that ‘Where instances of a particular collection of intrinsic properties (i.e., properties already, diagnosed from sensory information) tend to be grouped such that if some are present, most are, then other useful properties are likely to exist which generalize over such instances. Further, properties often are grouped in this way’ (Marr 1970 pp. 150–51). These ideas presaged much of the later work by others on neural network models of brain function, which invoke the intuition of learning as optimization (‘mountain climbing”) in an underlying probabilistic representation space.

A model at whose core is the tallying of probabilities of events needs an extensive memory of a special kind, allowing retrieval based on the content, rather than the location, of the items. Marr’s third theoretical paper considers the hippocampus as a candidate for fulfilling this function (Marr, 1971). In analyzing the memory capacity and the recall characteristics of the hippocampus, Marr integrated abstract mathematical
(combinatorial) constraints on the representational capabilities of codons with concrete data derived from the latest anatomical and electrophysiological studies. The paper postulated the involvement in learning of synaptic connections modifiable by experience—a notion originating with the work of Donald Hebb (see Hebb, Donald Oding (1904–85)) in the late 1940s and discussed by Marr’s mentor Brindley in a 1969 paper. Marr provided a mathematical proof of efficient partial content-based recall by his model, and offered a functional interpretation of many anatomical structures in the hippocampus, along with concrete testable predictions. Many of these (such as the existence in the hippocampus of experience-modifiable synapses) were subsequently corroborated (see the reviews in Vaina 1990).

2. The MIT Period

A consummation of this three-prolonged effort to develop an integrated mathematical-neurobiological understanding of the brain would in any case have earned Marr a prominent place in a gallery, spanning two and a half centuries (from John Locke (see Locke, John (1632–1704)) to Kenneth Craik) of British Empiricism, the epistemological stance invariably most popular among neuroscientists. As it were, having abandoned the high-theory road soon after the publication of the hippocampus paper, Marr went on to make his major contribution to the understanding of the brain by essentially inventing a field and a mode of study: computational neuroscience. By 1972, the focus of his thinking in theoretical neurobiology shifted away from abstract theories of entire brain systems, following a realization that without an understanding of specific tasks and mechanisms—the issues from which his earlier theories were ‘once removed’—any general theory would be glaringly incomplete.

Marr first expressed these views in public at an informal workshop on brain theory, organized in 1972 at the Boston University by Benjamin Kaminer. In his opening remarks, he suggested an ‘inverse square law’ for theoretical research, according to which the value of a study varies inversely with the square of its generality—an assessment that favors top-down reasoning anchored in functional (computational) understanding, along with bottom-up work grounded in an understanding of the mechanism, but not theories derived from intuition, or models built on second-hand data.

The new methodological stance developed by Marr following the shift in his views is summarized in a remarkably lucid and concise form in a two-page book review in Science, titled ‘Approaches to Biological Information Processing’ (Marr 1975). By that time, Marr came to believe firmly that the field of biological information processing had not yet accrued an empirical basis sufficient for guiding and supporting a principled search for a general theory. Remarking that the brain may turn out to admit ‘of no general theories except ones so unspecific as to have only descriptive and not predictive powers’—a concern echoed in one of his last papers (Marr 1981)—he proceeded to mount a formidable critique of the most common of the theories circulated in the early, 1970s, such as catastrophe theory and neural nets (the current popularity of dynamical systems and of connectionism, taken along with the integration of Marr’s critical views into the mainstream theoretical neurobiology, should fascinate any student of the history of ideas).

The main grounds for his argument, which was further shaped by an intensive and fruitful interaction with Tomaso Poggio (Marr and Poggio 1977), were provided by an observation that subsequently grew into a central legacy of Marr’s career: the understanding of any information processing system is incomplete without insight into the problems it faces, and without a notion of the form that possible solutions to these problems can take. Marr and Poggio termed these two levels of understanding computational and algorithmic, placing them above the third, implementational, level, which, in the study of the brain, refers to the neuroanatomy and neurophysiology of the mechanisms of perception, cognition, and action.

Upon joining the MIT AI Lab, Marr embarked on a vigorous research program seeking computational insights into the working of the visual system, and putting them to the test of implementation as computer models. Marr’s thinking in the transitional stage, at which he treated computational results on par with neurobiological findings, is exemplified by the paper on the estimation of lightness in the primate retina (Marr 1974); subsequently, much more weight was given in his work to top-down, computational-theory considerations. This last period in Marr’s work is epitomized by the theory of binocular stereopsis, developed in collaboration with Poggio, and presented in a series of ground-breaking papers (Marr and Poggio 1976, Marr and Poggio 1979). At that time, Marr also worked on low-level image representation (Marr 1976, Marr and Hildreth 1980), and on shape and action categorization (Marr and Nishihara 1978, Marr and Vaina 1982). Marr’s book, Vision, written during the last months of his life, is as much a summary of the views of what came to be known as the MIT school of computational neuroscience as it is a personal credo and a list of achievements of the second part of Marr’s scientific endeavor, which lasted from about 1972 to 1980.

3. Legacy

The blend of insight, mathematical rigor, and deep knowledge of neurobiology that characterizes Marr’s
work is reminiscent of the style of such titans of neuroscience as Warren McCulloch—except that McCulloch’s most lasting results were produced in collaboration with a mathematician (Walter Pitts), whereas Marr did his own mathematics. A decade after his quest was cut short, it has been claimed both that Marr is cited more than he is understood (Willshaw and Buckingham 1990), and that his influence permeates theoretical neurobiology more than what one would guess from counting citations (McNaughton 1990). Still, contributors to the mainstream journals in neurobiology now routinely refer to the ‘computations’ carried out by the brain, and the most exciting developments are those prompted (or at least accompanied) by computational theories.

In computer vision (a branch of artificial intelligence), the influence of Marr’s ideas has been complicated by the dominance of the top-down interpretation of his methodology: proceeding from a notion of what needs to be done towards the possible solutions. For some time, Marr’s school was identified with the adherents of a particular computational theory of vision, which claims that constructing an internal model of the world is a prerequisite for carrying out any visual task. The accumulation of findings to the contrary in neurobiology and in the behavioral sciences gradually brought to the fore the possibility that vision does not require geometric reconstruction. This encouraged researchers to seek alternative theories, some of which employ concepts and techniques that did not exist in the 1970s, or were not known to the scholars of vision at the time. These new ideas, in turn, are making their way into neuroscience, as envisaged by Marr.

On a more general level, Marr’s work provided a solid proof that a good theory in behavior and brain sciences need not have to trade off mathematical rigor for faultlessness to specific findings. More importantly, it emphasized the role of explanation over and above mere curve fitting, making it legitimate to ask why a particular brain process is taking place, and not merely what differential equation can describe it.

See also: Cognitive Neuroscience; Computational Neuroscience; Concept Learning and Representation: Models; Feature Representations in Cognitive Psychology; Information Processing Architectures: Fundamental Issues; Mental Representations, Psychology of; Neural Plasticity in Visual Cortex; Neural Representations of Objects; Perception and Action; Visual Perception, Neural Basis of; Visual System in the Brain

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Marriage

1. The Definition of Marriage

Marriage has been a central area of study since the beginnings of anthropology, as a main factor in explaining the variety of kinship systems (Morgan 1870, Rivers 1914). The institution of marriage, however, has not been easy to define as an anthropological concept.
Computational Neuroscience: A Window to Understanding How the Brain Works. “The brain computes!” declared Christof Koch, who explained at the Frontiers of Science symposium how a comparatively new field, computational neuroscience, has crystallized an increasingly coherent way of examining the brain. Adams, a biophysicist, designs models and conducts experiments to explore the details of how the basic electrical currency of the brain is minted in each individual neuron (Figure 9.1). He has no qualms referring to it as a bottom-up approach, since it has become highly relevant to computational neuroscience ever since it became appreciated “that neurons do not function merely as simple logical units” or on-off switches as in a digital computer. Start studying cognitive neuroscience. Learn vocabulary, terms and more with flashcards, games and other study tools. Thinking on how such models guide the study of the functioning human brain—including perception, memory, attention, language, and emotion (basic higher cognitive functioning)—uncover ingenious observation of clinical populations. Chapter 1: A Brief History of Cognitive Neuroscience. What is cognitive neuroscience? Combines the study of “Cognition” (process of knowing) and “Neuroscience” (study of the nervous system). Goal: To understand how the functions of the physical brain are associated with mental processes and yield the output of the mind. Origins of modern cognitive neuroscience date back to the 1600s and earlier. Called our ‘command center,’ the brain sets the rules for our lives, and controls our thoughts and actions. Despite extensive research, scientists still don’t know exactly how the human brain works, and what it hides in its darkest corners. What is our brain really capable of? And as humanity’s reliance on technology and computers grows stronger, can progress make our brains weaker? Or is the human mind more powerful than the most advanced computers? We ask a scientist in the field of neuroscience and the theory of mind—Tatyana Chernigovskaya. Follow @SophieCo_RT. Sophie Shevardnadze: Doctor Chernigovskaya, thank you for being with us. We’ve been really looking forward to this interview, since it’s always fascinating to talk about the things that make us who we are. Research o Brain emulation is the logical endpoint of computational neuroscience’s attempts to accurately model neurons and brain systems. o Brain emulation would help us to understand the brain, both in the lead-up to successful emulation and afterwards by providing an ideal test bed for neuroscientific experimentation and study. o Neuromorphic engineering based on partial results would be useful in a. The workshop avoided dealing with socioeconomic ramifications and with philosophical issues such as theory of mind, identity or ethics. While important, such discussions would undoubtedly benefit from a more comprehensive understanding of the brain and it was this understanding that we wished to focus on furthering during the workshop.