HISTORY OF COGNITIVE SCIENCE

CONCEPTS CLES: cognition, mind, knowledge, computation, mental symbol, grammar, rationalism, functionalism, computer, connectionism, formalization, representation, rule.

In spite of of its name, cognitive science is not yet a fully coherent and integrated science but rather a fairly loose coalition of largely independent disciplines, some descriptive and empirical (cognitive psychology, linguistics, neuroscience, cognitive anthropology), some speculative and foundational (philosophy), others both speculative and applied (artificial intelligence). What brought these disciplines together and still sustains their interdisciplinary cooperation is the dedication to explain, simulate and technically reproduce the workings of the human mind according to a distinct and rather well defined research program. This program has been _so far_ the animating spirit and the integrative force in the formation and development of cognitive science. I will call it the 'core program.' Around the core program there is a much looser and less coherent outer paradigm, or set of paradigms, which historically has prepared the ground for the core program, to which the participating disciplines have contributed their insights, results and methods, and still do, and from which challenges to the core program have emerged and are likely to do so in the future.

Surveying and understanding the history of cognitive science is no easy matter. Given the increasing popularity of the field, we already see the temptation of regarding varios past thinkers as cognitive scientists _avant la lettre_ just because they have proposed a notion or advanced a hypothesis that has, or can be read as having, a counterpart in current thought on mind and cognition. This temptation is understandable, since the history of the outer paradigm of cognitive science is practically equivalent to the history of all intellectual efforts to understand human cognition systematically. This would include the history of epistemology and philosophy of mind as well as the history of psychology, logic, cognitive anthropology and linguistics. The result, I fear, would be trivialization (for then all thought on cognition, mind and language is leading to cognitive science) and therefore failure to detect and understand the real historical contributors.

The truth is that not all past views on mind and cognition, and not even all those which clearly contain insights recognizable today as cognitive-scientific, have contributed to the research spirit of cognitive science. The latter has been shaped by a core program which represents a distinct and rather partisan perspective on cognition -- a perspective defined by some key and fairly restricted notions, assumptions and methods of inquiry. Accordingly, the history of the core program should have the much narrower task of reviewing only those past views which meet two conditions: (a) they not only appear to have directly contributed to or anticipated key elements of the the core program itself, and are acknowledged to have done so by the current practitioners of the program (the subjective condition); but (b), upon careful reconstruction, they also can be shown to have at least in part approached cognition the way the core program currently does. This article surveys a few historical connections between the core program and early views which meet these two conditions.

1. THE CORE PROGRAM

We can understand the core program of cognitive science in terms of several components: the basic question to which the core program provides an answer; the methodology in terms of which the basic question is to be answered; a general model of cognition which all the participating disciplines share and in terms of which the answer to the basic question is conceptualized; and a set of working hypotheses or assumptions which make this research program possible, plausible and successful. Each of these components has its intellectual history.

The Basic Question. Noam Chomsky is not only the leading linguist and a premier cognitive scientist of this day but also a sort of historical consciousness of the core program of cognitive science. The question which Chomsky regards as fundamental for cognitive science is the following: "How comes it that human beings, whose contacts with the world are brief and personal and limited, are nevertheless able to know as much as they do know?" This is Bertrand Russell's formulation of a question first posed by Plato (Chomsky 1975, p. 5). The Platonic connection is essential. Not only is the core program of cognitive science motivated by Plato's question but it proceeds to answer the question by making some of the same moves that Plato and the subsequent rationalist tradition made. To that extent, then, the prehistory of the core program can be seen as coextensive with that of rationalist epistemology (Plato, Descartes, Leibniz, Kant, Frege).

Plato's question is motivated by a certain notion of knowledge. The same is true of the core program today. The notion is that we do have knowledge of a distal reality, whether natural, social, linguistic or mathematical. (The skeptical notion that such distal realities cannot be known, or the solipsist notion that we are limited to knowing only our internal states, or the positivist notion that we are limited to knowing only our proximal states or what we can act upon, are notions inimical to the current project of cognitive science, and cannot be regarded as historical anticipations of the latter.) Yet our immediate access to, and the form in which we engage, that reality is only by means of proximal sensory stimulations.

If we have knowledge of distal realities, then Plato's question becomes two questions. For, in asking how such knowledge is possible, we are first asking about the sort of structures and processes which can deliver such knowledge from proximal information. We are specifically asking how these structures and processes manage to do it in the form they do, by way of concepts, images, logical forms, inferences, linguistic expressions, and other such encodings of information. This is a question about cognition. But in asking how knowledge is possible, we are also asking about the sort of system which can instantiate cognitive structures and run its processes, a system capable of cognition. The latter is a question about the mind.

The Methodology: From Knowledge to Cognition to Mind. With the basic question divided as suggested, the rationalist strategy was to proceed from knowledge to cognition and then to mind. More exactly, the strategy was to reason from an account of knowledge to the cognitive structures and functions capable of delivering knowledge, and from these to the nature of the mind containing such structures and functions. This, for example, is how Plato reasons from an account of our knowledge of Forms to a model of how such knowledge is encoded by innate representations, and then to the character of the encoding system, the nonmaterial mind. Similarly, Descartes, another major rationalist anticipator of the core program, uses the same strategy to reason from a form of knowledge (of the 'Cogito, ergo sum' sort) to the cognitive capability responsible for it (consciousness) and from the latter to the nature of the mind (immaterial).

The rationalist methodology of approaching psychological matters contains not only a well defined, level by level, top-down analysis but also a distinct method of theorizing at each of the levels. As noted, the top level of the rationalist analysis is that of a rational and abstract theory of an idealized domain of inquiry (knowledge). The next level is that of a speculative model of the structures and processes operating in the domain (the structures and processes of cognition). If we leave aside the particulars of the domain, we have the essential method of theoretical science, from the axiomatized geometry of the Greeks, which so much influenced Plato, to the mathematical physics of Galileo and Newton, which so much influenced the early cognitivist philosophers, from Descartes to Hume, Leibniz and Kant.

The methodological insight of theoretical science is to identify and isolate in a domain of inquiry some basic, invariant and explanatory properties and relations, distinguish them from their undisciplined, superficial and contextual manifestations, and ignore everything else, including counterevidence, as so much "noise". This first step then is one of ontological simplification. The next step consists in rationalizing and idealizing the simplified ontology to the point to which an abstract and preferably formalized (logical, mathematical) model or representation can be proposed in terms of which precise questions can be asked and powerful and coherent hypotheses can be formulated and tested by formal derivation as answers. In the empirical sciences this method is often called "the Galilean style" (Chomsky, 1980, pp. 8-9; Haugeland, 1984, ch. 1). Thus, not only did Galileo and Newton shape their simplified ontology around a few pervasive and explanatory properties and relations (such as absolute space and time, instant velocity, uniform acceleration, mass, force, and the like) and their regularities, but also and crucially chose to model this ontology in the powerful and successful language of formal representation (geometry, algebra, calculus, etc.). This is the first and most important component of the Galilean style. There is another one, on which more later, which has to do with the manner of formal representation and its semantics.

It is no surprise then that that the philosophical pioneers of the core program should have adopted the Galilean style of theorizing about cognition. In his celebrated autobiographical fragment in Phaedo Plato was the first to explicate the scientific method as deduction from abstract assumptions and models, and urge its application to our understanding of the human mind. In modern times, both rationalists, such as Descartes and Leibniz, and empiricists, such as Locke, Hobbes, Hume, thought that the task of the philosopher of mind was to produce a Newtonian-like science of knowledge and cognition in the Galilean style.

The spirit of the top-down, level by level analysis, and the Galilean style of theorizing, are very much at the heart of the methodology of the core program of cognitive science. In its contemporary form, this methodology was first and clearly articulated by Noam Chomsky (1975; 1980) in his early works on grammar, by Allen Newell (1982) in his foundational work on artificial intelligence, and recently by David Marr (1982) in his work on computational vision. The starting point is the first level of knowledge, in the form of visual knowledge of distal objects, linguistic knowledge of what an interlocutor or a text says, and the like. The task of the analyst at this level is to provide a rational and abstract theory of what this knowledge is, and under what constraints and by what means it could be achieved. Chomsky's theory of grammar and Marr's theory of vision are in this sense theories of grammatical and visual knowledge, respectively. The second level is that of cognition. The task here is to define the cognitive means (structures and operations) by which, and the constraints (rules, algorithms) under which, their utilization yields knowledge. Finally, the third level of analysis concerns the mind. At this level the analyst asks how the structures and operations of cognition identified at level two are or can be physically implemented in some sort of hardware (Pylyshyn 1984).

Knowledge: Distal, Dedicated, Innately Programmed, Constructive. The spirit of the theory of knowledge of the core program is captured by the formula "what we know is not what we sense". This formula in fact summarizes several working hypotheses directly and openly borrowed from the early rationalist tradition. One hypothesis, as noted, is that we have distal knowledge which defines the semantic properties of our cognition. This knowledge has very specific or dedicated forms (perceptual, logical, linguistic) which make available to us the distal properties of the objects of cognition. Another hypothesis is that neither those distal properties nor the forms in which we represent them are present in the proximal stimuli, and hence cannot be simply copied or grasped by sensory perception. The core program follows Plato, Descartes and Kant in resisting the idea that we could be constituted so as either to directly resonate to and pick up or else simply learn the universal truths about the distal world from the available sensory information. This is why an Aristotelian epistemology, which makes the contrary assumption, cannot be regarded as anticipating the core program; or why contemporary Aristotelian manifestations in the outer cognitive science paradigm, such as the influential Gibsonian view of direct, "resonating" perception (Gibson 1979), have met very stiff resistance and sharp criticism from the defenders of the core program (Fodor&Pylyshyn 1981; Marr 1982; Pylyshyn 1984).

Two further rationalist hypotheses complete the level one theory of knowledge that the core program inherits from rationalism. One of them is that the format and means of representing our distal knowledge, as well as some basic constraints on that knowledge, are innate. The rationalist argument is familiar from Plato to Descartes: the sensory stimuli do not and cannot represent the distal knowledge which we possess; but the sensory stimuli are the only basis for learning or acquiring our knowledge; therefore, a good deal of the latter's properties cannot be learned sensorily and therefore must be innate. If anything, says the other rationalist hypothesis, our distal knowledge must be constructive, not stimulus-driven, and becomes effective by activation, reconstruction or inference initiated by the sensory stimuli.

The theory of knowledge proposed by the core program of cognitive science continues this line and recognizes knowledge as distal, dedicated, innately programmed, and constructive (Chomsky 1975; 1980; Fodor 1975; 1983). This is perhaps the point where we should pause for a moment and speculate. If what we have said so far is plasuible, then it seems that in the 17th and 18th century the rationalist philosophy of mind not only was operating in an intellectual climate very much similar to the one which has recently led to the emergence of cognitive science (Chomsky 1972, pp. 8-9) but had practically all the ingredients with which to cook up a successful cognitive science. It was asking the right questions, making the right assumptions, and using the right methodology to answer those questions. The spirit of the enterprise was scientific and some of its guiding lights (Descartes, Leibniz, Kant) were themselves first rate scientists. They were also beginning to understand the right notions of mathematical logic (Leibniz) and natural languages (Descartes, the Port Royal grammarians), which now prevail, of cognitive architecture (Hobbes, Kant), and were even contemplating automatizing thought processes (Descartes, Leibniz) and implementing them in thinking machines (Leibniz). So why didn't they do it?

There are probably many reasons, some intellectual, other social, institutional and perhaps personal. Among the intellectual reasons, two appear to stand out. One, to which we will return shortly, is that modern rationalism had not taken the possibility of a material mind seriously, and had instead spent much energy and time arguing against it. The other reason, relevant at this point, is that their theory of knowledge failed to integrate and account for the genuine and indispensable functional role of the sensory information in the larger picture of cognition. That was a damaging mistake. It is one thing to argue, as the rationalist tradition had, correctly, that the sensory information cannot deliver the distal knowledge we have, in the form we have it, or that that knowledge cannot be learned, or inductively generalized, from the sensory information. It is quite another thing to find for the sensory information no more significant a role than that of mere causal trigger of an already available and completed knowledge. That was the mistake. Its damaging consequence is that, at the first level of analysis, the sensory information is not included in the (rationalist) knowledge equation, and therefore at the second level, it does not figure as an equal partner in the resulting model of knowledge-delivering cognition.

The core program of contemporary cognitive science does not make this mistake. While generally agreeing with the rationalist notion of knowledge, the core program advances the further hypothesis that the sensory stimuli play a major role in knowledge; they reveal under computational analysis the distal information that is constitutive of knowledge. Thus, for example, I decode what you say, and know the meaning of what you say, by analyzing the acoustic data which reach my ears. Likewise, in vision, I come to know what lies ahead of me by analyzing the light input on my retina. So the question that arises, still at the level one of theorizing, once things are seen this way, is how this inferential analysis is accomplished. The answer given by the core program is that the analysis is carried out by computation (i.e. formation and transformation) of representations.

Cognition. According to the methodology examined earlier, the next question to ask is what sort of structures and processes can execute such computations of representations. This is a question at the second level of analysis, that of cognition. The core program's answer is that the representations take the form of symbol structures, and the computations the form of syntactic operations on such structures. This answer is motivated by the notion that distal properties can be inferred from proximal stimuli only if the information about the former is extracted step by step from successive encodings of the latter. For this to happen, the information to be extracted must be encoded explicitly in a form which the extracting (computational) processes can recognize and operate on. The prevalent view of the core program is that such explicit encodings take the shape of discrete units, or symbols, which are assembled serially into more complex structures, and transformed into further structures, under rules and algorithms of formation and transformation. These rules and algorithms are sensitive only to the discrete (simple or compositional) form and serial position of the symbols, and therefore can be regarded as syntactic (Chomsky 1980; Fodor 1975; Marr 1982; Pylyshyn 1984). Let us call this the 's/s model' to emphasize the notion that cognition is viewed as syntactic manipulation of symbols.

In the history of thought on mind and cognition, a s/s model plays two major explanatory roles. One, just outlined, is <u>cognitive</u> and consists in accounting for how information is computationally extracted from the stimuli by means of rules and algorithms to form representations of distal objects and properties. The other role, which we will discuss in a little while, is <u>implementational</u> and consists in explaining how matter can cognize, that is, how matter can be mind. The cognitive role of the s/s model of cognition was anticipated by a number of modern philosophers. Although, as noted, they failed to see that computations on symbol structures are needed to extract and analyze the information contained in the sensory stimuli, they had other important and mutually reinforcing incentives to think of cognition in terms of a s/s model.

We have mentioned earlier that the Galilean style of theorizing requires a formalized representation of the simplified ontology of a domain of inquiry. What is important to note now is that the Galilean style uses formalization in a cognitively abstract and arbitrary manner. This is the other component of the Galilean style of doing science. Galileo not only proposed to analyze the deeper structure of physical nature (the primary qualities) in terms of mathematical relations among quantities, but used a formalization method, geometry, both naturally, for representing spatial properties, and arbitrarily, for representing other nonspatial physical properties such as times, speeds or accelerations. Descartes also used algebra (arbitrarily) to represent geometrical relations and thus space. In so doing, Galileo and Descartes, and others after them, divorced mathematical representation from its apparently privileged subject matter (if any). They thus paved the way for the more general and revolutionary notion that mathematics and logic apply to reality not in virtue of their resembling that reality, and that generally a formal representation need not have any instrinsic or natural aboutness or semantics (Haugeland 1975, ch.1).

This insight remained to be applied to cognition. Two philosophical theses, much admired in the 17th century, made this application possible. One was the well known rationalist thesis that many of our concepts and certainly our formal concepts (of logic and mathematics) do not resemble and cannot originate in the external objects and properties which we sense, which is why those concepts must be innate. Like the words in a language or the symbols of a mathematical representation, our concepts and thoughts must be arbitrary (or conventional) symbols manipulated under rules. Both Descartes and Hobbes embraced this conclusion, one which is very dear to the core program in contemporary cognitive science. In his Meditations Descartes, notoriously, draw from this position the dramatic implication that the way the world is does not make any difference to what our mental representations represent -- an implication now known as "methodological solipsism" and placed by Fodor (1980) at the philosophical center of the core program.

The other thesis which allowed the formalization component of the Galilean style to work for cognition was that thinking was regarded as being more like linguistic discourse (Hobbes) or mathematical/logical reasoning (Descartes, Leibniz). In either case, thinking is combinatorial under rules -- an idea which intuitively favors, and can be explained by, a s/s model of cognition. As Descartes realized, thoughts and other cognitive structures are symbolic representations of the formal or mathematical sort (Haugeland 1975, ch. 1). With this position on the nature of cognition so clearly articulated, one cannot help but speculate that the history of cognitive science could have taken another course if the developments just examined would have also linked with the Port Royal's theory of "rational grammar", itself very much inspired by Descartes' approach to cognition. The Port Royal theory not only looked beyond the data of language use to deeper organizing principles of grammatical knowledge, but in doing so it distinguished between (what we call today, due to Chomsky) surface and deep structures, and even anticipated transformational rules which map the latter on to the former (Chomsky 1972, pp. 14-17). Unfortunately, the Port Royal theory of grammar seemed never to have connected in the right way with the other 17th and 18th century advances in understanding cognition.

The Mind. It takes a real system, made of physical bits and pieces, to instantiate cognitive structures and processes and run the program of cognition. What sort of system must it be? In particular, if the program of cognition is understood in terms of a s/s model, what can physically implement symbol structures and their syntactic manipulations? This, in the methodology of the core program, is the third level of analysis, that of the mind. We know today what the answer is, even though we do not have the complete theory of this answer. A human brain is an implementer of a s/s model and so, practically speaking, is a computer. But 17th century philosophy, which came the closest to create a science of cognition on a par with astronomy and physics, could not have answered this way. Its rationalist wing preserved the s/s model of cognition as the only one able to explain knowledge but metaphysically favored dualism, hence an immaterial mind, while the empiricist wing favored a metaphysical reduction of mind to physical matter, hence the notion of a material mind, but in this way sacrificed the s/s model of cognition which cannot belong to the vocabulary of physics.

And yet, retrospectively, the 17th century thinkers seemed fairly close to the notion of a material mind needed for their cognitive science. As we saw, they had the right methodology in place, the example of other sciences where the same methodological spirit allowed for a materialist approach, and they also had a model of cognition whose implementation is now perceived by the core program as favoring materialism while preserving the irreducibility and autonomy of the psychological properties and laws of cognition. A number of modern philosophers (Hume, the French materialists of the 18th century) contemplated or even wanted a sort of reductive "mathematical mechanics of the mind", on the assumption that the mind is nothing but particles in motion subject to attraction, repulsion, and other forces. Yet Hobbes alone seems to have been prepared to consider the notion of a material yet symbolic-and-syntactic mind, as he thought that the theory of mental mechanics should obey the s/s model and apply to physical events only classified as symbols and syntactic manipulations (Hobbes, 1651, part I, chs. 1-5; Haugeland, 1975, ch. 1). This is very much in the spirit of the "physical symbol hypothesis" formulated by Newell and Simon, two of the founders of artificial intelligence (Newell&Simon, 1975).

What Hobbes could not determine in terms of his theory is probably what prevented Descartes from accepting the possibility of thinking machines. Both held the view that thinking is rational symbol manipulation under rules, and that the rationality embodied in rules must reflect what the symbols mean (their semantics). Logical rules, for example, are rational because (among other things) they are truth preserving, a semantic virtue. Both Descartes and Hobbes could not find a way of consistently placing meaning in their picture of mechanical and symbolic/syntactic cognition. Haugeland (1975, pp. 36-40) calls this "the paradox of mechanical reason". For contemporary cognitive science brains and manmade computers are real life solutions of this paradox; the task of the analyst is to understand what the solutions amount to. For the early rationalists, the paradox meant either dualism or simply an end of explanation; for a materialist, dualism is the end scientific of explanation.

As Noam Chomsky points out, 17th century thought was accustomed to end-of-explanation notions such as Newton's occult notion of gravitation or action at a distance or Descartes' equally occult notion of mind as nonextended, immaterial substance (Chomsky 1972, pp. 7-8). In fairness to the 17th century, it should be noted that philosophers and foundationalists today are still puzzled by facts of consciousness, intentionality and by the paradox of mechanical reason itself, as recent discussions about an intrinsic semantics of minds versus a derived semantics of computers (Dennett 1987) or about the Chinese Room argument (Searle 1980) vividly indicate.

An Interim Period. Under the retrospective light of the core program, we have suggested that the recipe for a successful cognitive science needs to combine at least the following ingredients: a rationalist top-down analysis which proceeds from knowledge to cognition to mind; an equally rationalist notion of distal knowledge that a model of cognition must make intelligible; a Galilean style of simplifying the ontology of knowledge and formalizing the analysis of the optimal conditions in which such knowledge can be obtained; a s/s model of cognition which can satisfy or approximate the optimal conditions of knowledge acquisition; and some account of the real systems (minds) whose architecture and capabilities could execute the functions of cognition in a given environment. Following historiographical accounts such as Chomsky's (1972; 1975; 1980) and Haugeland's (1985), admittedly partisan since made from the perspective of the core program, we have speculated that, the notion of a material mind aside, the 17th century seemed to have almost all it needed to produce a successful cognitive science the way it produced successful physical science. But it wasn't to be.

It was only in this century, towards the middle of it, that the core program of cognitive science took a distinct shape and became influential by contaminating and bringing together several disciplines under a unifying research paradigm. What developments are responsible for this outcome? To answer this question, we must take a brief and admittedly superficial historical measure of what has happened between the so promising 17th century and the middle of the current one. In terms of the outer paradigm of the cognitive science, quite a lot happened: biology, psychology, linguistics, anthropology and the neurosciences came into being. As a result, the amount of sheer knowledge about cognition and the brain increased dramatically. Yet from the explanatory and clearly partisan perspective of the core program, the answer is likely to be "not that much happened". All that impressive accumulation of descriptive knowledge would not necessarily, and in fact did not, contribute to a theoretically novel understanding of cognition and mind.

The story of language is often taken as a revealing example. Philosophers, logicians and linguists have since the middle ages added an impressive amount of data and speculative models to the collective knowledge of language. Yet most people would agree that it was Chomsky in the midfifties who, from the standpoint of cognitive science, asked the right questions and proceeded to answer them in the right way, thus revolutionizing our understanding of language. In so doing, as he acknowledges so often, Chomsky revived the methodological spirit of the 17th century and shaped it into what we are calling here the core program. If Chomsky's own diagnosis is right, then the centuries in between not only did not contribute much to the linguistic part of the core program but in fact regressed with respect to the remarkable insights of the Port Royal grammarians (Chomsky 1966; 1972).

One could extend this diagnosis to other segments of cognitive science. One can count Kant's as probably the last effort of modern rationalism to build a cognitive science. Kant had a more realistic notion of knowledge than his rationalist predecessors, and, unlike most of them, he clearly saw the role of the sensory experience in the knowledge equation. This insight in turn allowed him to propose at the second level of analysis a more elaborate and adequate model of cognition, including his revolutionary views of (what we call today) the functional architecture of the mind: that the way we are functionally built not only constrains what we can know and how, but also contains primitive capacities and operations (spatial and temporal sensibility) which provide an implicit form of knowledge. Yet, like the Port Royal's insights, Kant's went practically nowhere, as philosophy led by Hegel and the German romantics was turning its unfocused and undisciplined attention to other, essentially social and cultural matters. From the standpoint of the core program, the postkantian theories of knowledge and cognition, including those (such as behaviorism) which led to the emergence of a scientific psychology generally regressed with respect to Kant and his 17th century predecessors by asking the wrong questions in the wrong order and using the wrong methods.

False Pretenders and Real Contributors. Particularly in linguistics and psychology the revolution brought about by the core program in the mid 20th century had first to criticize, unlearn, and replace the theoretical and methdological habits of the interim period. (Chomsky's critique of Skinner's behaviorism is a well known example.) It had also to take its theoretical distance from important developments in the outer paradigm of the emerging cognitive science which, for some time, seemed very promising candidates for the unifying role of a core program. One of them was cybernetics, the science of self-regulating and goal-directed systems. The fact is that cybernetics carves up the domain of cognition differently than does the core program. Cybernetics is more interested in how living or mechanical systems organize themselves and operate to achieve their goals, rather than in the structure of the knowledge such systems have and the nature of the cognitive resources they must deploy to obtain and represent their knowledge. Another short-lived candidate was (statistical) information theory. Again, this proved to be a theory of a different domain, for, in its objective version, it is interested in the amounts of information transmitted, irrespective of its meaning, while in its subjective version, it is interested in the measure of novelty or uncertainty that a information has for an agent. Neither version is programatically interested in, and hence prepared to conceptualize, the representation, computation, and content of information.

Our historical discussion has documented the intellectual forces which constitute the core program of contemporary cognitive science. If one had to speculate on what brought these forces together, concluding the synthesis that the 17th century failed to achieve, one ought to mention as the first major contributors the two big C's, Chomsky and the Computer. We have said enough about the former, and are fairly familar with the nature and the impact of the latter. We should only mention that the computer came to be regarded by the core program workers as some sort of mind incarnate and therefore a technical solution to a metaphysical problem that the 17th century thinkers failed to handle properly. In its early and still dominant von Neumann architecture (serial syntactic operation, storage of program as explicit data, etc.), the computer is also being seen as an implementational proof that the s/s model of cognition works in real life. Needless to add, for better or worse, the (von Neumannn type) computer also turned out to be an extraordinary fertile metaphor and intuition pump (Dennett) for our thinking about mind and cognition in s/s terms.

At a slightly further remove, two other 20th century intellectual developments contributed significantly to the emergence and validation of the core program by generally shaping the conceptual Zeitgeist around the core program, and more concretely by preparing the conceptual ground for the breakthroughs in computer science and technology as well as in linguistics and cognitive psychology. One such development is mathematical logic which not only brought a new understanding of the nature of logic, mathematics and formal knowledge generally but also spawned new and powerful theories of computation, programming languages and formal models as shared tools for linguists, cognitive psychologists and workers in artificial intelligence.

The other development is more philosophical. It has to do with the maturation of a philosophical position, eventually acknowledged at the second level of analysis in the methodology of the core program, that the essence of cognition resides in the nature of the functions being executed rather than in the nature of the hardware which executes the functions. This position came to be known as <u>functionalism</u>. It was anticipated by behaviorism (which ignored the hardware of cognition just as it ignored its internal states) and confirmed by the computer which, by being able to execute the same cognitive functions as a human brain, showed that the nature of the hardware is irrelevant. All that matters in understanding cognition is the program, that is, the set of rules which governs the execution of the cognitive functions.

As a background position, functionalism helped the core program in more ways than one. It emphasizes program at the expense of hardware, thus allowing the idealization and strong formalization favored by the Galilean style. It legitimizes an autonomous and irreducible level of theorizing and explanation for cognitive science among the other sciences of nature. And, so far, it has favored the s/s model of cognition since it is with symbols and syntactic computations that we can best and most radically distinguish hardware instantiation from functional role.

The functionalist position vindicates to some extent the early rationalist notion that the hardware of cognition is not important. We have earlier speculated that this notion may have deprived 17th century cognitive science from succeeding. What is different in this century? Or is it different? We can asnwer this question by concluding with a new development which has emerged as a serious challenge to the core program, a challenge directed against the marriage between functionalism and the s/s model of cognition.

BEYOND THE CORE PROGRAM

Neural Connectionism. In the 1940's Warren McCulloch and Walter Pitts produced a logical model of the operations and connections of neural networks. That not only showed that the brain functions as a computer, since it can implement a logical program, but also that artificial neural networks may compete with the standard von Neumann architecture for a better simulation and understanding of human cognition. In the same period Donald Hebb (1949) has shown how the brain acquires knowledge over time by encoding information in the connections it forms gradually among cell networks. These early neural speculations didnot enter the mainstream cognitive science, as they were facing an unfriendly and immensely successful core program and a different and competing (von Neumann) computational philosophy. But they have been revived recently in an increasingly popular research program, called connectionism, which portrays itself as an alternative to the core program.

The connectionist program retains (at the first level of analysis) the key idea of the core program that cognition is computation of representations, but denies (at the second level) the s/s model's claim that computation is syntactic and representation symbolic. Connectionism also reacts against the von Neumann architecture of the mind, and argues instead that the real brain operates in a parallel fashion through computational processes which behave dynamically and continuously, as opposed to sequentially and discretely (McClelland et al. 1986; Churchland 1986). The connectionist methodology, which goes against the top-down and functionalist spirit of rationalism and its current embodiment, the core program, maintains that a realistic bottom-up inspiration from the way the brain works provides an alternative and a better model of cognition, and hence of how knowledge is acquired, than does the core program. The advocates of the latter have been quick and forceful in countering that connectionism is only a hardware implementation doctrine, relevant only at the third level of analysis (Fodor and Pylyshyn 1987).

The debate between the core program and connectionism is likely to dominate the concluding decade of this century, and possibly bring about some major changes in the methodology and practice of cognitive science. Other dissidences are likely to emerge as well. Cognitive science has entered a phase of healthy maturity. Yet there is no question that historically it was the core program, anticipated and made possible by a long and distinguished rationalist tradition in epistemology and philosophy of mind, that made cognitive science what it is.

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<u>renvois possible</u>

Cognitive Science, Chomsky, Linguistics, Cognitive Psychology, Connectionism, Computation, Artificial Intelligence