Csaba Pléh (Hungary)

THE COMPUTER AS AN INSPIRING AND A LIMITING FACTOR IN THE CONCEPTUAL DEVELOPMENT OF PSYCHOLOGY

Machine as a model of man

It is a general feature of the modern Western image of man to treat the then available machines as possible analogues to man. This mental pattern extends the relevance of machines to man, and interprets man as a fountain, as a clock or as a steam-engine. This tendency is supplemented, however, by two further factors. First, the idea is raised that after all, man is still not an engine of this type. He cannot be, e.g., interpreted as a determined clockwork since man is free, man is an initiator of actions. Second, the opposite idea is raised as well, according to which man creates and interprets machines on the analogy of man. Thus, when machines are treated as the measure of man, a full circle of analogies is present: the machine was built on the analogy of man, and this analogy is re-applied to man. (See Crosson, 1985, concerning this general issue of machines applied to man.)

When the inspirational and limiting role of computers on psychological thought during the last 40 years is raised as an issue, it is evident that there is nothing radically new and specific to the computer age in the mere fact of searching for machine analogies and the cyclic disillusionment with the analogies which once promised to be fruitful. The new aspect concerns the *nature* of the machines proposed this time as sources for analogy. Psychologists, among other people, discovered the computer as an information processing machine. The possibility to characterize our own cognitive processes in a neutral way, irrespective of the 'vehicles of thought,' is recognized in it. This analogy is far from innocent. It is not innocent with regard to the machine since it raises the issue of equivalence from time to time: to what extent is the behavior of the machine identical with that of man if their performance is equivalent. (For a critical presentation of the strong versus weak equivalence issue see Pylyshyn, 1984).

Neither is the analogy innocent with regard to man. It presupposes that the working of the human mind is united and unitary like the working of machines. It presupposes further that this unitary nature can best be grasped in *symbol manipulation.* Finally, in the beginning, the relationships between human thought and the environment was rather neglected. The environmental information is presented to human thought in early cognitive models of psychology in a rather elaborated way as well as is the case with machines. In later years this becomes the issue of perception and interface, respectively, in a unitary model of cognition.

In the following, the limitations of this analogy will be taken up from the human side: I will limit myself to issues of the modelling of cognition, putting aside other relevant issues like the social side of cognition, the emotion-cognition interface and the like.

The **computer** as a **support of objectivity in the cognitive revolution**

In reviewing the inspiring and limiting role of computers in psychology, the broadest framework is provided by a thirst for models characteristic of the early days of the cognitive revolution in the sixties. The essence of this shift of emphasis - indeed, it may be an exaggeration to call it a revolution - was the *(re)discovery of man as a modelling creature.* And the seiences of behavior gradually have become sciences of modelling the modell-making features of the human mind.

There were many reasons underlying these changes that are listed here without providing evidence (see about them Segal and Lachmann, 1977). The prevailing neobehavioristic mode of thought in experimental psychology has become liberalized. It has become tolerant both conceptually and experimentally. Technological developments called for an image of man as an information processing system. Research on perception (the *New Look* school) has pointed out the complicated interactions beyond the local stimulus that are responsible for perception. All of these paved the way for a general shift of attitude. One important element among all these factors was the role of *formal sciences and modern linguistics* in the development of cognitive psychology (see Lachmann, R., Lachmann, J. L., and Butterfield, E. C, 1979 and Smith, 1990).

Mathematics, computer science and linguistics played an active, liberating role in the cognitive turn in the following way. For the psychologist trained in a positivistic flavour and reluctant to talk abut the inner world, these disciplines made it possible to have something to say about inner world without the stigma of subjectivism. The cognitive turn has become victorious not by claiming direct access to consciousness or by a revival of introspection. Rather, it has analyzed the internal world through indirect routes. The availability of conceptual approaches that provided an option to talk about inner reality, while keeping the aura of scientific rigor, has been a great help in finding these indirect routes. Earlier, during the fifties a similar role was played by information theory. The (then) New Look borrowed concepts like coding and recoding capacity from the formal analysis of communicative systems, i.e. from *information theory.*

The concepts of algorithm and heuristics were also been taken over by cognitive psychology from the formal sciences. The same is true for the *representation theory* so central to cognitive psychology. It has been accompanied by the import of logical models into psychology. Propositional calculus shows up not only in the trivially most relevant domain of psychology (in the study of language understanding and in the analysis of human inference), but it plays a central role in the analysis of memory storage as well. Human knowledge has a propositional character. Memory, for example, re-emerges in psychology not as an unstructured mosaic of ideas but rather as a rich pattern of predicate-argument networks that give structure to knowledge (Collins and Quilian, 1969). The formal inspiration quite naturally shows up in the logical analysis of thought processes as well. This took the form of analyzing human categorization with graphs representing a series of hierarchically embedded decisions (see e.g. Feigenbaum and Feldman, 1963.) Likely logical models show up in the analysis of problem solving first proposed by Herbert Simon and Alan Newell (for a summary see Newell and Simon, 1972). In this approach, human problem solving protocols are analysed into if - then type logical reasoning chains (that are, in their turn, interpreted in the AI models as production systems).

From the point of view of psychology proper in all these cases what one witnesses is a transfer of an analytic language from another field to the study of individual mind that allows an analysis of the *structure of performance* instead of an introspective account of the inner world. The logical type of analysis reveals what man *had to do* in order to produce performances of a certain kind. This attitude is similar in one regard to the tacit knowledge proposal of Polanyi (1962). We know more than we can tell. However, while Polanyi emphasizes the soft, unformalized aspects of *skill* (cf. Crosson, 1985), what is in contemporary terminology a kind of implicit memory, the early cognitive trend starts from the idea of *formal* processes (algorithms and hidden factual knowledge) unavailable to consciousness and introspection. As Dreyfus (1990) points out, however, even Polanyi becomes partially formal when he looks for the sources of tacit unverbalized knowledge in rule-like maxims. But, as Nyiri (1992, Chapter 5) summarized it recently, in practical knowledge, or skill, there always remains an application level that is not organized like a formally statable rule. We shall see later on that this problem is similar on the action side to the now famous symbol grounding problem (Harnad, 1990) on the input side: cognitive categories as description of the world in a representational theory of mind have somehow to be anchored to the real world through non-symbolic processes (i.e. through sensation).

After a while, this formal inspiration became a real force in research, not merely a cover-up when wandering on the muddy terrain of thought. When the seemingly machine-like explicit systems of psychologists were compared with real machine systems, it became clear that the psychological model quite frequently was not explicit enough. Thus, the psychologist was forced to make more and more explicit her or his model of what man does and what types of information are in fact used in a given performance. This has become rather straightforward in the design of question answering or language understanding systems. One of the exciting tasks facing the psychologist here is to make explicit all those inferential chains that make our stories coherent (see for a theoretical attempt Schank and Abelson, 1977, for some experimental studies Pléh, 1987, and the volume edited by Graesser and Black, 1985). As we shall see later on, the application of a simplistic machine model, and traditional formal models to psychology had to face two types of obstacles, both on the "periphery" of the model. Perception and everyday social knowledge are not that easy to model by machine, and not easy to make explicit.

It is worthwhile noticing here a certain duality inherent in the cognitive approach. Cognitive psychology makes *information* and *meaning* the focus of research. Meanwhile, in its purest form, it does not care about the processing system. This focussing on information would inherently drive the study of cognition towards an engagement that does not treat man as a mere object. All of this implies a kind of a Platonistic approach that presupposes the existence of pure forms of knowledge. At the same time, however, this Platonistic view of man still tends to treat man on the analogy of a machine. The main formal support and inspiring force for the cognitive movement in psychology is a machine, the computer. This feature shows some clear affinity of the cognitive trend towards the traditional mechanical view of the world that treats man as an object. Many internal tensions of the cognitive view and many external criticisms of it are in fact based on this duality: man is treated as an information system which is characteristically a non-object, while at the same time man is treated on the analogy of an object.

The linear computer and the information processing approach

The most basic analogy between the point of view of cognitive psychologists and the computer has been the trend on the part of psychologists to treat human cognition on the analogy of a linear information processing system with a single central processor (for instance a Neumann-type computer). The human cognitive system, like a traditional computer, was also supposed to have a limited capacity short term storage and a long-term background store that has a (practically) unlimited capacity, and its mode of operation is basically sequential. It is rather revealing that this image of a sequential machine is usually supplemented with the remark "with the exception of the obviously parallel sensory processes." With this remark, however, the issue of relationships with the outside world is usually over. These sensory processes are dealt with only to the extent that they provide a set of features for the description of objects.

The dominant cognitive approach for about 15 years has been the theoretical framework outlined in the seminal book *Perception and communication* by the British experimentalist, Donald Broadbent, in 1958. Essentially, this position claims that human cognition consists of coding steps corresponding to more and more abstract informational features. In "processing" an incoming word, for example, first its physical features are identified (acoustic and graphic representation). The filtering function that corresponds to selective attention would work on the output of these processes. The system is parallel and has a large capacity at the preattentive stages. This is supposed to be followed through a sequential coding process by a limited capacity short term store. Then, in semantic coding, all the information stored about the given word in the long term memory system would be mobilized.

The stages and the stores corresponding to them are not mere abstractions postulated for the sake of organizing data. The inspirational role of the machine analogy in fact appears in this aspect. Psychologists have devoted long series of experiments to the identification of each of these stages. In the analysis of the filtering function, for example, the classic issue of whether we can indeed make several things in parallel is reformulated as a model according to which in the early stages preceding recognition there is indeed parallel processing through multiple channels, but this is followed by filtering in the recognition stage, recognition being a strictly sequential process. The detailed experimental questions deal with issues like what kind of representation is being formed at levels below **full** recognition, what features are and could be used in filtering, whether filtering is partial or total, and so on. The corresponding experimental paradigm is the cocktail party situation (continuous listening to parallel verbal messages). The characteristic experimental situation corresponding to short term storage is false recognition of letters following a few second interposed activity.

This general metaphor of the Neumann-type computer in psychology, beside having a positive impact upon research, has introduced or reinforced *several limitations* in the psychological research on cognition.

1. The overwhelming nature of sequential processing

This is the most controversial issue today. We shall return to it later on in connection with the controversy around parallel and sequential processing.

2. The idea of a limited capacity

Our resources are limited in a unified manner. That is to say, all mental computations use the same central processor, they have to share a common capacity. With respect to limitations, all cognitive processes can be reduced to a common denominator. This idea is still with us even in the avant-garde propositions of the seventies that made processing context and task dependent in contrast to the mechanical automatic image of the original model. These new proposals create an opposition between automatic and controlled processes, the latter ones requiring effort as first proposed by Kahnemann and Tversky (for a review see Kahnemann, 1973). This new approach still preserved the basic idea that we have one single limited cognitive resource that has to be divided between different tasks. Here is one experimental example: while listening to sentences, the recognition of irrelevant noises is slowed down if they are presented around the end of the sentence. TLe reason for this is that if our resources are busy with the analysis of the sentence (this is the case around the end of the clause as opposed to jits beginning) no more resources are left to analyze the irrelevant material (Fodor, Bever and Garrett, 1974). Thus, in the common denominator of the shared limited capacity, even the processing of a buzzing tone and the meaning of a sentence have something in common.

In the eighties, both the idea of parallel processing (e.g. Rumelhart and McClelland, 1986) and that of modularity (Fodor, 1983) challenged the concept of limited capacity as the common denominator in cognition. The capacity limitations, as Allan Allport (1980) very aptly put it, are not due to a neutral central processor, but are due to the competition of different tasks for the same executive system, i.e. for the control of speech.

3. The idea of stores with a fixed order and parameters

The linear-sequential metaphor has proved to be of limited validity in memory research as well. First, it has become obvious that in the classical view, a correspondence was suggested between the representational form and the temporal sequencing of stores. Left-to-right sequencing in this way corresponded to representations going from the physical code towards the more abstract ones (Table 1).

Table 1

Storage systems and forms of representation in traditional cognitive psychology

Very short term	Short term	Long term
physical features	name codes	semantic codes

This conception has clearly relied on the machine analogy of operative and background storage. Three considerations have led to questioning of this general image. In opposition to the bottom-up linear sequencing metaphor of human cognition, models emphasizing top-down processes, the anticipatory role of higher order organization showed up, most notably in the form of different schema theories.

These theories are, in a way, structural formulations of the New Look ideas on perception (for a clear exposition see Rumelhart, 1980). It has also become evident that the temporal fate of different codes and representations is a flexible process. The context and the task have a determining influence over the retention of different codes. The physical code, as in the famous matching experiments of Posner (identity judgements of AA vs. Aa after 0 to 2000 ms delays) that seemed to disappear after 1 s may be present for longer times provided that physically identical pairs are much more frequent in the set (Posner, 1986). According to the levels of processing theory proposed by Craik and Lockhart (1972) flexible coding processes should be postulated rather then boxes with fixed parameters and a fixed sequence to account for the dominance and availability of different representations.

The working memory conception of Baddeley (1976) also emphasizes flexibility in the memory system. Although it presupposes stores, it treats their interrelationships in a functional rather then in a preassigned way.

It has also become clear that in models of recognition long term stored knowledge cannot be assigned to such a late phase in the process as the original model has suggested. If we want to account for, say, the recall of words after a few seconds (the so-called short term memory performance), we have to postulate a temporary activation of the knowledge store (the long term store) that is prior to short term storage. Thus, in a way contrasting with the initial model, the workings of the 'long term box' somehow precede the workings of the 'short term box'.

4. Machine and human parsimony

It is a rather peculiar way to map machine thought onto human information processing when psychologists start from machine parsimony. Furthermore, its starting point is the early machine model that considers memory to be the most expensive ingredient. Thus, all data should be stored only once. This conception had a dual effect on models of semantic memory interpreted for psychology. The paradigmatic example is the famous knowledge representation and retrieval system proposed by Collins and Quilian (1969). Due to the hierarchy relations between nodes *(canary —» bird -» animal)* predicates valid over the extension of the superordinate node are only stored by that node (e.g. the *canary* node has no separate predicate about flying; only the *bird* one has). Experimental studies to verify this model compared decision times for specific predicates *(The canary is yellow)* with decision times for generic predicates *(The canary can fly).* Early studies supported the theory: specific predicates had faster reaction times (RTs) than generic ones. It did not take much time to realize that the real situation was more complicated. There are subordinate concepts that have fast RTs for certain generic predicates. Also, not all subordinates have the same RTs for a generic predicate (compare *Swans can fly* with *Eagles can fly).* It seemed to be safer to propose a dual parsimony principle for humans. In the human processor, redundancy is avoided, but decision speed plays a role as well. Frequently used informations has multiple representations in the network (Smith, Shoben, and Ripps, 1974).

This modification is a good example for the general workings of the machine analogy within psychology. We simplify the human model by using ideas derived from the machine. Later on, contradictions are observed between the simplifying model and experimental results. Therefore, the oversimplifying model is refined. However, both cases are fruitful in this process. Simplification and revision are two steps in the endless process of approximating reality, and flirting with the machine and disillusionment from the machine are examples of this diadic process. In the reversed engineering conception of cognitive research the ideal is to start from the performance (the behavior) of the system and find actual computational models that are increasiingly more and more equivalent in their performance to the human mind. The approach as fruitful as it is, certainly has to face some basic boundary limitations: e.g. could we ever try to include experience into the reversed engineering model? Is modelling the physical structure (the body) a realistic aim (see about these matters Harnad, 1993)? But even at levels where reversed engineering works, it seems to be that the actual computational models it uses tend to show this cyclicity of being inspired by actual machines and then rejecting the given machine model for a new one. Polanyi (1967) in his antireductionist stand concerning life implies in this respect that although we have to look for mechanical (machine) models what we shall actually find will be mechanisms that manifest irreducible boundary conditions as in the case of life interpreted in a physico--chemical framework. Similarly, when he discusses the logic of tacit inference (Polanyi, 1969), he claims that when we are using a machine model for the functioning of the body, we are only using some aspects of biological functioning: the function itself cannot be understood starting from the machine.

Uniformity and multiplicity in thought

Some of the most basic dividing factors in contemporary cognitive psychology could be related to the way psychologists deal with the initial simplified linear machine as a model of cognition. Two characteristic and rather central dividing factors will be selected here: the issue of *uniformity* and *sequentiality* in thought. In both cases the rival alternatives, while questioning the modelling value of machines with a traditional architecture, are themselves flirting with a new machine metaphor or they indeed do implement new architectures. Thus, they preserve the fruitful relationship between the study of man and machine in a productive way: they turn to new types of machines to support human imagination.

Concerning the uniformity-multiplicity issue from the beginning of cognitive psychology on, one can witness two different attitudes. The uniformity idea was always dominant from the beginning of the empiricist movement on, but from time to time there were strong voices of dissent making claims for a more quality oriented view of the human mind postulating several different types of mental processes. The first modern multiplicity view was presented by classic faculty psychology (see papers in the volume edited by Smith, 1990). In modern times this attitude was revived by Sir Frederic Bartlett (1932). His multiplicity centered approach was aimed to demonstrate for the behaviorists as well as for the classical associationists that the human mind was too complicated to be accounted for by simple principles of connection formation. Similar ideas were proposed in early cognitive psychology by Neisser (1963) in a largely forgotten paper where he emphasized that in psychoanalytic theory, in the experimental study of cognition, and in the study of human abilities as well, one can differentiate between ordered and unordered, analytic and holistic cognitive processes as basically different qualities.

At the birth of modern cognitivism proper the opposition between uniform and multiple views of mental functioning took the form of an opposition between associative and structure bound processes. Chomsky and his followers opposed learning theory principles and language acquisition, the latter being characterized by self organization and rule formation rather than association and environmental determination (Chomsky, 1959; Miller and Chomsky, 1963). This was the beginning of a straightforward dual view of mental functioning: there is a mechanistic and a structure dependent mode of functioning, the latter being characteristic of complex forms of behavior-like language. From the late sixties on, however, this view of dual organization was gradually replaced by an overarching unifying trend within the same structuralist group. Specifically, a conception took form suggesting that all interesting processes should be dealt with within the framework of structure-dependent processes and hypothesis testing rather than association. This conception replaced the duality of learning versus rules, association versus structure with an overwhelming structuralism (Chomsky, 1968, Fodor, 1968).

This view is not shared by the entire cognitive trend. It has become gradually clear that the cognitive trend is radically divided in this respect, and its division might very well be interpreted as a division of opinion with regard to the explanatory power of the unitary symbol manipulating machine. The idea that human cognition follows basically the same principles everywhere has taken definite form. Its most explicit version is the theory proposed by Herbert Simon and his associates. According to this view, the very same general problem solving principles show up in every human process. Human cognition applies so-called production systems to repeated problems. Their structure is the same in every problem area. They look for an input of a certain kind and from thereon they arrive at the result as a consequence of a chain of reasoning. The neutral language of the human mind is the language of logical calculus. The train of thought is the same, be it a question of chess playing, sentence understanding, or even typewriting. At the same time, our entire background knowledge system participates in all cognitive processes (Simon, 1979; for a new synthesis along these lines see the volume of the late Allan Newell, 1990).

Parallel with this process, the conception inspired by generative linguistics - itself being a unifying conception for a while - gradually became the most straightforward opponent of unitary theories. This took the form of the modular conception of mind based on the model of modern linguistics. Modularity, of course, has several different sources and interpretations on the contemporary scene starting from the electronic idea of modules to the concept of neurological modules as put forward e.g. by Szentagothai (1975). One of the basic features of this proposal is the emphasis on a unitary kind of organization in the cerebral cortex. The units in the cortex serving different functions basically have the same kind of organization; that makes their genetic determination feasible. They function as a highly interrelated structure, with many more internal connections then external ones. They communicate to other modules only the net result of their computations. The cognitive modularistic conception takes over the idea of encapsulated computational units from the neurological doctrine. It proposes, however, modules of a much larger scale. And at the same time, it puts the emphasis not on the identity of structure, but on the qualitative differences in function.

This conception was most clearly articulated by Jerry Fodor (1983). He started from a critical analysis of a specific shortcoming of the classical 'unified' information processing positions, namely that they are in trouble with regard to the specific processes of perception. They just suppose that the analysis gives a description of the stimuli in terms of specific features, but the features and the. process of their extraction are not clearly articulated. For an information processing paradigm there are no quantitative differences between the treatment of data from vision and from audition, for example. However, says the modularist claim, no matter how similar the processes are for a concept formation algorithm if it has to do with a series of decisions based on visual features when it has to classify objects into the categories of triangle and square, and when it has to classify certain stimuli as salted and sweet, these are only apparant similarities (as any phenomenologist should have long known). Patterns can be regarded as equivalent to each other only to the extent that they are treated as descriptions. In this case, however, nothing was said about the way the descriptions themselves were obtained.

Phrased in the idiom of the machine world, the modularity conception draws into focus an important aspect left out of traditional machines: the relationship between representations and the outside world. Fodor (1983) and Pylyshyn (1984) define as "input systems" those supposed neural components that perform the separate tasks of coding incoming information independently of each other in a prototypically genetically determined order and interact with each other only at the level of their outputs. These micromachines are encapsulated, impenetrable also in the sense that knowledge in the traditional meaning of this term cannot influence their workings. That is, knowledge, expectation and other contextual factors have an influence only on the results of these computations and never on their inside operations. This conception is generalized by. Fodor into an overall modular view of the human mind. Not only perceptual processes, but most of our cognition in general is organized according to the principle of input systems: most of the human mind consists of encapsulated, task specific modules that fulfill their tasks with remarkable speed and in a reflex-like automatic way.

From the point of view of machines, this conception suggests that several task-specific, small processors coexist in our mind, and the results of their computations are made available to a General Problem Solver-like symbol manipulating system. Thus, a little room is left by Fodor for experience-bound general cognition. But he does this unwillingly and the domain of this factor is gradually narrowed.

Concerning language, for example, the modular thesis claims that context or frequency has no effect on the immediate mechanisms of word recognition. These factors have only a post hoc effect modulating the ease of word use. In a similar vein, there is no interaction between the lexical, syntactic and semantic components of understanding; all of them operate as self-contained systems. Interactions only appear on the level of their outputs, on the level of the results of their computations. The two diverging views here are the entirely interactionist view (this is the one supported by the general cognition idea) and a modular view that postulates totally autonomous subprocesses. For a presentation of the views and the supporting empirical evidence see the volume edited by Garfield (1987).

Historically - and Fodor is very conscious to take up here a classical position - this conception is a revival of the eighteenth century faculty psychology of Franz Gall. (Concerning this aspect of Fodor, see Pléh, 1985.) And this reference, in its turn, leads us towards classical theories of the multiple action views of the human mind, including not only Reid and the Scottish school, Kant and Leibniz, but even the scholastic teaching about faculties. (See Smith, 1990.)

In this broad context, the multiplicity view proposed by Polanyi (1962) for human nature is rather parallel to the modular view. When he proposes different approaches to the world, among them a rational-discursive (propositional) and a more experience-bound, sensation oriented approach, he stands on the same side with the multiplicity people and with the claim for qualitatively different cognitive mechanisms. Polanyi, inspired, among other things, by the organizational ideas of Gestalt psychology (see Ujlaki, 1992) in his antimechanistic and anti-elementaristic world view, quite naturally stood for a multiple view of mental functioning in several respects. He postulated - without considering the machine minded cognitive trends, but seriously considering and challenging the neopositivistic implications of cybernetics (e.g. Polanyi, 1969) - that beside explicit processes which are possible to be reconstructed in a logical way one has to suppose several types of hidden processes like the ones underlying skill, the empathic understanding of movement, intuition, etc. (Polanyi, 1968).

Dreyfus (1990) clearly presents Polanyr as a precursor for a dynamic view of cognition. According to this view, in contrast to the entirely Socratic representational theory of cognition where all our mental acts should be composed of operations clearly statable in terms of explicit rules, real skillful cognition is always based on tacit knowledge and non-focal consciousness. Not only do we always have non-stated sides to what we know, but the important cases of knowing how (as opposed to knowing what) are based on maxims rather then rules. Polanyi is on the side of a view on cognition where knowledge and the process of knowing is more than what is statable in the form of a propositional calculus. We should add that his emphasis on nonexplicit thought is not irrational, but it includes large subsymbolic components (perception) and tacit inferential components (practical inference).

The modular approach is put forward in opposition to and as a challenge to the New Look view of perception that has played such a great role in the formation of the entire cognitive movement. The essence of this conception is that perception depends on several factors beyond the local stimulus: our expectations, frequency, the actual context, the motivational significance of the signs all contribute to perception (Bruner, 1957). The modular conception, on the other hand, treats perception as inseparable from knowledge (Pylyshyn, 1984). In this sense, it denies continuity between different levels of cognition. In this respect, the computational theory of vision proposed by the late David Marr (1982) shows some parallels with the modular conception concerning the structure of form and space perception. Marr also proposes a solution with algorithmic steps that are independent of experience with the given individual pattern and context. *Nota bene,* in this process of reconstructing the process of human vision he also relies on machines in two respects. First, the general framework of the computational theory proposes that the first step is to clarify the logical structure of the task to be solved by any syst< *PI* capable of vision independently of the properties and constraints of the system. This is followed by a description of actual algorithms and' by the implementation of these algorithms in humans and in machines. On the other hand, Marr also relies on machines in everyday research practice. He is constantly willing to learn from artificial modeling (sometimes from its failures). Vision is understood if we are able to reproduce it.

From a historical point of view, all of these debates and divergent opinions remind us of the debates that have been with us at least since mid-eighteenth century regarding the experiential and innate theories of space perception. There is one new feature, however, most clearly seen in the work of Marr. The idea of formal analysis brings an abstract level into the structure of research endeavour. The first task of the scientist is to make a conceptual analysis into the problems, which is the 'computational level' of the logics of research. There is a one-to-many relationship between this level and that of the algorithms actually used by humans. In principle, several realizations could be made available for the very same computational theory. That is the reason why the work of Marr has become an influential model in cognitive science. This is a new pattern, slightly different from the one proposed by early artificial intelligence researchers where the starting point was the program rather, than the structure of the task. It is a conscious realization of the thought provoking possibility of machines on an abstract level.

A similar conceptual model characterizes modern linguistics. There too, the need for an abstract characterization of the system and the products is emphasized preceding considerations of the actual implementation of this model in human speech performance. In language this duality is between the abstract theory describing a generative grammar of the given language as a theory of competence that is to be followed by theories of how competence is used in actual performance (Fodor and Garrett, 1966). This duality originally proposed by Chomsky (1965) some thirty years ago sometimes even takes the form of a triple system resembling the three levels of approach poposed by Marr. The grammatical theory, the theory of competence, is to be followed by a theory about the algorithms representing that competence (this is sometimes referred to as a theory of competence mechanisms, sometimes as an abstract theory of performance, e.g. by Fodor and Garrett, 1966), and this is followed in turn by an account of actual sentence processing and production, in a theory of performance (Watt, 1970). However, and this is a very important similarity, as Miller and Chomsky (1963) have emphasized a long time ago in connection with language, the theories of performance (say, the implementation level) have to embody a grammar, a theory of competence. Or, to put it in another way, it needs a theory about the requirements that any implementation theory has to fulfill (Pylyshyn, 1972). In all of this, in the case of language for a longer time, and in the case of vision quite recently, the machine, rather than giving with its physical constraints a limitation to the phantasy of the researcher, stimulated the need for an explicit abstract theory, which is the last formal kind of inspiration taken over from issues of computation.

Sequential and parallel processing

During the last decade another approach showed up that is a rival both of traditional architecture and that of modularity. Concerning its psychological content, this is a radical neoassociationist way of thought (cf. Pléh, 1992). Similar to classical architectures (for the characterization of psychological models as 'architectures', see Fodor and Pylyshyn, 1988) it advocates a unified and unitary model of cognition. The key to this unity, however, is not the language of logics and rules, but the world of networks based on mere contiguity. The unity of cognition is provided by a theory of representation where only facilitating and inhibiting connections exist between the nodes interpreted as abstract neurons. The apparent complexity of mental life would be explained by the fact that nodes and sub-networks coexist at different levels (e.g. in the case of word recognition, on the level of features, letters, and words) and the connecting lines between them may produce rather different activation patterns: there is top-down as well as bottom-up and collateral (reading pr facilitates the processing of *o)* facilitation as well as inhibition (reading pr inhibits the activation e.g. of *a* and *u* in English). Knowledge, however, remains in all of these additions, a mere activation of a partial network (McClelland, 1988), rather than the application of rules. In the case of reading, for example, the classical approach would interpret effects like an easy reading of pro- as the result of phonotactic rules, while the connectionists stand for a system where only connections between an enormous number of individual units are postulated. This is the basic content of the new approach with regard to representation **that** is aptly referred to as connectionism. (The starting volume for the connectionist movement is

Hinton and Anderson, 1981. For an exposition of the development of the movement and its relationship to other approaches see the volumes edited by Pfeiffer, et al., 1989 and by Brink and Haden, 1989.)

This is supplemented by the fundamental idea of overwhelming parallel processing (Feldman and Ballard, 1982). This is exposed most explicitly in the conception of Rumelhart and McClelland (1986; McClelland and Rumelhart, 1986). This feature gives the name of the most active group within the more general connectionist movement: *PDP, Parallel Distributed Processing.* The parallel processing appears in this framework not as a particular issue (e.g., the extent of parallel processing before and after attention as it was treated in classical cognitive psychology from the Broadbent model on), but as the basic feature of all cognition. In the familiar case of written word recognition, for example, starting from the letters, all possible word candidates (e.g. all words that are consistent with the first letter) would be activated in parallel, and the most probable one would gain victory due to multiple activation (both from each of its letters and from the activation of all partially compatible words as well) and also because the rejected candidates would get inhibitory input as well (e.g. from the non-corresponding letters).

This new ambitious project has generated several penetrating discussions (see the volumes edited by and Pinker and Mehler, 1988, and by Pfeifer et al., 1989). Two of these critical aspects are relevant in the present context. First, while the theories of parallel processing try to get rid of the metaphors inherent in traditional machine architecture, at the same time they try to prove their theories by constructing new machines. In their research strategy they rely on three foundations. They try to use data from psychology, machine network construction, and neurology. The connections between neurology, the computational networks and mental processes is assumed to be rather strict. In this respect, they take up the lead of McCulloch and Pitts (1943). In the original proposal the binary neuron was made responsible for the unitary binary principles of logics in mental life. This neuronal structure explained the most basic scaffolding of the mind. In a similar reasoning, in the new conception, the most general argument in favor of overwhelming parallel processing is found in the famous so-called *100 steps rule* (Feldman and Ballard, 1982). Essentially, this rule again claims a fundamental isomorphism between neuronal and mental organization. It relies on the insight that the neuronal parameters of individual neurons are in the order of magnitude of milliseconds, while usual the human recognition and reaction times are in the order of hundreds of milliseconds. Their magnitude relationship does not allow more than 100 steps to be arranged in a sequential manner in the modelling of any given cognitive task. Since most usual conceptions imply many more elementary steps one has to suppose parallel processes.

Following this lead, on the one hand, massively parallel machine architectures are constructed (see for this Fahlmann, 1988, and the full volume edited by Kowalik, 1988). From the psychological point of view, in the theoretical models, the abstract neurons and their connections represent directly the coding steps involved in given cognitive tasks (McClelland, 1988). Thus, the now traditional flirting between machines and psychology is strongly reinforced here. Simply, machines with a classical architecture are replaced by machines with new architectures as the inspiring forces.

Another important aspect is the sincere negative approach of connectionism to the issue of rules in mental life. Rumelhart and McClelland (1986, 1987; see also McClelland, 1988) are especially clear concerning language that they treat rules not as internal, inherent laws of the mental system but as external characterizations of the products of the mental system. The task, they claim, is exactly to produce mechanical models that imitate and thereby eliminate from the proposed mechanism the level of rules. One does not need too much phantasy here to realize that these proposals have led to the unearthing of old animosities in linguistics and psycholinguistics (see the Pinker-Mehler 1988 volume, and especially Fodor and Pylyshyn, 1988, and Pinker and Prince, 1988). It is of interest on the conceptual level that the storms raised around and by the connectionist camp have revived and combined two debates that have been with us for decades. Are rules inherent in the machines or are they present only in the mind of the designer, and - transplanting the machine model to man - are rules indeed in the human mind or are they only to be found in the researcher's model about behavior? The classical issue of the mental reality of rule systems, as proposed, for instance, by generative grammar early on (Chomsky, 1968; Fodor, 1968), not only gets a fresh start in this new debate but it creates a parallel epistemological issue concerning the rule governed nature of machines and man.

Rules or connections: Some basic **criticism of connectionist models**

The most interesting criticisms of connectionist theory all concentrate on the issue of structure vs. elements. On the contemporary scene this takes the form of discussions whether there are rule governed behaviors not reducible to simple connections or habit formation. The generativist-structuralist critics point out that their traditional rejection of associative and stochastic principles for the explanation of language (Chomsky, 1957; Miller and Chomsky, 1963) is still valid concerning the neo-connectionist models, and that these latter ones are unable to deal with rule-like regularities in a clear way.

Table 2

The juxtaposition of connectionist and classical cognitive

architecture according to Fodor and Pylyshyn (1988)

Connectionists	Classical view
nodes	descriptions
only causal relations	rich relationships
(history of excitation)	(language of thought)
excitation paths	rewriting rules
structure independent units	structure dependent entities (constituents)

Fodor and Pylyshyn in their critic of connectionism, summarized in Table 2, clearly show that the basic limitation of connectionist models is their lack of structure. One can characterize this feature in several ways:

> Models based on patterns of (co)excitation cannot differentiate between two concepts being active simultaneously and them being in a given relation (like IS, PART OF, etc.) This was attempted to be solved by labeling the graphs in "classical" network models.

A connectionist representation has no clear syntax (lack of structure).

The associationism of connectivist models situates the human mind at the mercy of the arbitrary unsystematicity of the world: it allows any connections whatsoever. It is worthwhile to remember that Max Wertheimer (1922) in one of his theoretical papers on Gestalt psychology also criticized what he called the "mere existential relationships" responsible for association in classical associationism. No essential or meaningful relationship had to exist between the to-be-associated elements. He proposed that this was only true in extreme situations, in certain limited cases. On the whole, it had to be replaced by meaningful and top-down organization in mental life. As Fodor and Pylyshyn put it today: "All it (i.e. the connectionist model) can do is build an internal model of redundancies in experience by altering the probabilities of transition among mental states" (Fodor and Pylyshyn, 1988, pp. 49-50).

In order to account for the systematicity of mental phenomena one has to go beyond this, to postulate structure-sensitive mental processes. The basic flow of connectionism is parallel to the flow of all assocationism from the classical associationist accounts of the mind through Hull (1943) to Hebb (1949) and Osgood (1963): associations, being insensitive to structure, have a hard time reconstructing semantic coherence of thought. Why not give up their explanatory power and replace them with internal organization, or structure?

In a more permissive formulation, Lachter and Bever (1988) also conclude that connectionist accounts are associative in nature. However, being parallel and allowing for associations at different levels, they provide for an enormous amount of elementary habits. But habits never become rules. However, "It is equally obvious that some behaviors are habits" (Lachter and Bever, 1988, pp. 243-244). Connectionism can be claimed to be a description of that (lower) level of behavior. Habits and rules should still be differentiated, as was proposed a good 30 years ago by Chomsky (1959), and the associationistic account should be reserved for habits.

Simple and complicated in a new light

It was mainly the pitfalls of machine modelling and artificial intelligence (or, to be more good hearted, their difficulties) that have directed attention towards the fact that earlier on one thought of human specificities in a short-sighted way (see about this Dehn and Schank, 1982). Classical psychology developed a rather definite sensualistic conception concerning the relationships between simple and complicated. The more stimulus independent something is, the more complex and higher the process is postulated to be. According to this image of working from the outside world inward, the achievement becomes more complex and more human. Thus, thought is assumed to be more complex and more human than perception. However, machine intelligence had shown us that processes that were supposed to be of the highest and most human type were rather easy to model even if not necessarily in a strongly equivalent way. Logical calculus and mathematical proof are classical examples to this effect And psychology traditionally treats them as higher order functions specific to humans.

As we have alluded several times before, perceptual achievements are rather difficult to model on machines. Just think of the modest results in computer vision or automatic speech understanding. This factor concerning machines had a twofold inspiring force with regard to psychology as well. First, psychologists have realized that the world of transducers, i.e. the subsystems assuring our connection to the outside world, is in fact very complex and complicated. Their contribution to the representation of the outside world cannot be dealt with as a trivial achievement (by just telling that they somehow provide a description of the stimulus), since exactly the genesis of this description becomes one of the key issues.

Besides becoming the driving force behind the general popularity of modular models, the recognition of the complicated nature of perception has led to the realization that seemingly low level systems may be specifically human as well. All that we witness, especially in connection with modularity, the computational theory of vision and the complexity of 'low level vision' (Julesz, 1984), means that the relationship between simple and complex is certainly not trivial in humans. Anything human can be as complicated as the most abstract levels of complexity, ft is of non-trivial interest here that besides the perceptual world, in fact mundane reality, our everyday knowledge and its use in understanding the world, proved to be the greatest challenge for AI models (Schank and Abelson, 1976; Schank, 1982). We may have to conclude that even in the study of cognition one has to overcome human vanity. We may have to admit that what seems to be specifically human (e.g. the effect of language on the perception of the world) is not specifically human due to its being complicated but due to its intersubjective, communicative origin.

The apparent non-success of the machine model to model non-algorithmic and non-propositional knowledge and the resulting reconsideration of what is specifically human and what is simple and complex has some natural resonances in Polanyi's work. The whole idea of tacit knowledge being central to our knowledge of the world, the emphasis on skill and perception are all consonant with the non-conscious schema based view of cognition. Historically, it is rather telling that not unlike Polanyi, Frederick Bartlett (1932), who first formulated the schema based view of cognition in psychology, also started from the analysis of skill and bodily function and extended this analysis into an overall conception of knowledge and memory.

Body and mind in the light of machines: Functionalism rediscovered

Relationships between machines treating information and man raised the issue of the relationships between body and mental life in a new light, more precisely under a rediscovered new light Using the terminology of Kripke (1972) the contemporary question is phrased as follows: can one postulate a rigid designation between the mental realm and human brain physiology (is there an identity there that is valid over all possible worlds) or - using a more traditional idiom - is there a strict identity between human cognition and brain processes provided that machines are also able to show evidence of intellectual achievements? The answer to this question has basically led to a renewal of the classical Aristotelian type of functionalism (see Fodor, 1981, and the volume edited by Block, 1980). What used to be soul as the form of bodily functions appears now as soul being a program, a set of instructions to run the system, the software running on the hardware, if you like.

The following line of thought led to the renewal of functionalism in the traditional sense as regards relationships between man and machine. Is the 'machine thought' characterizing the information processing approach indeed a viable route to understanding the human mind? Specifically, is it a sensible approach to take experimental data - mainly reaction time data - as the point of departure and to postulate on the basis of them a stupid machine that only takes into account the factors under the control of the experimenter and would produce similar results following algorithmic steps? When this kind of model was formed, it was assumed that an explanation was created for the procedure under study. Functional models in an information theoretic sense pretend to be an explanation while in fact they are only new descriptions. Arguments external to the functional model are in fact needed to conclude that the subjects had indeed followed the proposed strategy. When looking for explanations, one has to leave the traditional framework of the cognitive laboratory and use biological functions and culture. The information processing model certainly presents important constraints: it clearly shows the kind of complexity the explanatory factors (e.g. psychophysiology) have to cover. It does not show the explanatory solution itself, however.

Different types of *explanatory biological models* showed up, basically corresponding to the two usual types of biological reductionism in psychology. One takes a long step and looks for evolutionary bases of behavior, while the other takes a shorter step and looks for the immediate physiological mechanisms of behavior. The first is the evolutionary theory of human cognition. Interestingly enough, on the contemporary scene there are some attempts to combine the two approaches, and have not 'merely' a Darwinian explanation of behavior over the range of millions of years, but to extend the selectionist paradigm to neurophysiology proper over the range of a lifetime. Evolutionary theories of cognition are proposed in the sense that the Darwinian type of selection is postulated in the individual somatic life to account for the genesis and stabilization of neural circuits responsible for cognition and perception (Changeux, 1983; Edelman, 1987).

The other kind of biological interpretation, a direct physiological interpretation that treats cognitive mechanisms as reducible to discrete physiological events in the brain, also underwent important changes lately. The traditional silent assumption of all psychophysiology, especially electrophysiology has always been a kind of event reductionism when we were looking for neural correlates (?), equivalents (?), or bases of given cognitive events that result, for instance, from pressing an FT button. However, in the idiom of the last decade, this type of physiology has been supplemented or - in the eyes of some - even replaced by a new type of neural talk. Cognitive mechanisms are expressed as computational solutions that function over networks composed of abstract neurons. This approach is most characteristic of the connectionist group (see McClelland, 1988, and Pfeifer et al., 1989, for a clear expression of this) where it is overtly claimed that this new kind of thought speaks a neural language rather than a *lingua mentis* of Fodor (1975). Thus, the traditional symbol manipulating machine paradigm is replaced by a subsymbolic brain language. It is of course a matter of debate whether this brain talk is really about the neurons, or about a subsymoblic level interpreted in an abstract and not necessarily neural way (see about these solutions Smolensky, 1988 and Clark, 1989). Are not the abstract neurons simplified to the extent that it becomes unlicensed to talk about the brain at all? The details are not important for us at this point It is relevant to note, however, that this kind of new braintalk - both the evolutionary and the network version - has become so prevalent during the last years that a new materialist approach evolved in the philosophical interperation of these developments that sometimes refers to itself as neurophilosophy (Churchland, 1986; about the interpretation of this new eliminativism see the volume edited by Lycan, 1990).

This kind of direct biological anchorage is in a way counterbalanced with functionalism that is biological in principle but mental in practice. There are several versions of functionalism on the contemporary cognitive scene. One is a type of machine functionalism that basically claimed that type identity was untenable: a mental event is not necessarily always identical to the same brain event. A better image to analyze body-mind relations would be to see a similarity to the relationships between functional states of a machine and the corresponding (variable) physical processes (Putnam, 1960; Fodor, 1968). Another type of functionalism is nearer to the classical biologically minded one: it starts from the apparent teleology of mental life. (See about the different varieties of functionalism Block, 1980, Lycan, 1990, Putnam, 1989).

Not ignoring the important divergences in the interpretation of functionalism, one could summarize this line of thought in the following way. Mentality is indeed a form of organization of neural processes. It has to be characterized functionally as a certain type of information processing only to look later on for the actual systems that accomplish this performance and how do they in fact do this. Beside the computational theory of Marr (1982) already referred to several times, the functionalism put forward by Jerry Foaor (1981) also belongs to this camp. Beside proposing a physiological metaphor, this approach also reverses the traditional line of influence between physiology and psychology and basically questions the reductionism inherent in some of the physiologizing models. In particular, this approach assumes a three level analysis of cognition. The computational analysis (or the grammar to that effect) characterizes the task concerning what has to be done in order to understand sentences, recognize shapes and so on. The algorithmic characterization that (among other facts) relies on data from experimental psychology, provides us with a functional analysis of the how: how do we proceed to solve the given task phrased in terms of information processing stages. Finally, this is implemented by psychophysiological research and computer science (for machines in the latter case and by humans in the former case).

A simpler although misleadingly simplifying metaphor to characterize this is the application of the software-hardware opposition to the study of mind-brain relationships. The psychologist is presented as the scientist of natural softwares who is looking for a functional description in terms of symbol manipulation. Doing this, she/he presents the physiologist with a task: show how the given hardware is able to solve the given processing. It also raises the issue whether our machine is an entirely flexible one with no or very little system implemented (the traditional empiricist view that is partly echoed in present day connectionist models) or a machine that has a built-in basic processing mode that is part of its hardware (binary logic, universal grammar, the language of thought or whatever as part of our nervous system.) This corresponds, of course, to the traditional rationalist-innatist position. We are able to use other modes of information processing, other softwares, but the latter would all be secondary processing modes (see Block, 1980).

The different interpretations of functional ism of course touch upon many other issues. First, in a historical sense, the diverging interpretations make sense historically as well. Functionalism has as its direct antecedent and source not only mentalistic trends like Chomsky's philosophy of language and the neutralizing attitude of cognitive psychology and cognitive science that tries to make as little substantial commitments as possible. An equally likely and traditionally even more naturally given antecedent is the Darwinian functionalist psychology and biology. Some of the controversies are due to the fact that many functionalists (like Fodor, 1968, 1981, Block, 1980) are 'structuralists' in a traditional sense, while others (e.g. Dennett, 1991) are inheritors of a Darwinian functionalism with an eye on the origin and function of intentions and teleology in the mind rather than just mental structure interpreted in itself.

Another background feature of the contoversies is that while most of the functionalists combine a psychological or computational and a philosophical training, most of the advocates of a reductionist-eliminativist way of thought are people who are socialized in the practice of physiology and the neurociences. Due to these differences in tradition and in the content of the respective theories the two approaches present themselves as divergent Ways of thought regarding progress in science as well. Basically, in the eyes of most functionalists, the proper way to study cognition is from psychology (linguistics, cognitive science etc., the softer disciplines) towards physiology. It is the psychologist who gives to the physiologist the task to be explained. The reductionist camp, on the other hand, presents a rejuvenated version of the traditional belief that the proper way to study cognition is from physiology (neuroscience etc.) to psychology up, and it is the study of brain that should have the keys and the strategic lead in understanding cognition. The physiologist presents tasks and solutions to the psychologist, and for that matter, even to the mathematician as the debate between Changeux and Connes (1989) shows a case where the neurobiologist claims even the origin and development of mathematics is to be explained by a neural Darwinist model.

Regarding the issue of research style and how to proceed in science, the new functionalism and the (ideal) computationist approach broke with three traditional lines of thought. They got rid of an alternative inherent in old-fashioned AI research that builds strictly from the bottom-up. They have broken with physiologizing in a bottom-up way, and (most of all) with any fetishistic usage of reaction time data gained from traditional experiments in cognitive psychology. With the computational level of analysis, they present an abstract characterization of the performance (the functions) as the primary starting point for a study of cognition. Logical analysis has to precede empirical data gathering. The starting point should be neither a given machine nor a given program, but rather the logical analysis. With respect to the research affinity between machine thought and human cognition, functionalism in the general sense and the need for an abstract analysis (computational models) have proved to be the most promising kind of machine inspiration in psychology and in cognitive studies in general. In our present belief, this kind of functional characterization indeed gives a neutral description of knowledge that is independent from the presently prevalent metaphors and models. In the machine or information dilemma, the abstract, Platonistic inspiration regains its deserved position (that, by the way, was there from the beginning on in the work of people like Frege). We are not entitled to believe, however, that after a while this neutral nv del won't show up to be just another metaphor.

With regard to Polanyi, this kind of antireductionism is in accord with the idea so forcefully protected by Polanyi (1962, p. 31, see also Dreyfus, 1990) that it is a primary task to try to reveal the structure of the silent, unconscious skill of the expert when we aim to understand a cognitive function rather then to start with some pre-formed conception about that structure.

One specific historical remark is relevant here. The kind of functionalism proposed today was prefigured in tenns of analytic philosophy by Ryle (1949) and by the Hungarian psychologist Schiller (1947) in a behavior centered context half a century ago. Although they were not talking about functional models of the mental (and, therefore, Ryle is usually critized as a logical behaviorist), their functionalism sounds very modern if we trade behavior for cognition. To phrase it in everyday tenns, their view corresponded to a naive materialism that is Darwinistic on the one hand, and despises direct physiological reductionism on the other:

(i) . mental phenomena are realized of necessity by some material system;
(ii) this is not necessarily the human nervous system, however;
(iii) the very same function could be realized by different material systems (think of humans and computeres both doing simple calculations);
(iv) thus, as a research strategy the function has to be first clarified and then it is the task of the biologists to find out what part of the brain could fulfill this function and how it might work.

This kind of functionalism was born far away from actual computer science, most of all in the realms of philosophical discussions. However, for the computer minded cognitivist this is quite good. It represents the practice where someone could be a dedicated software person without paying any attention to the hardware. The psychologist can also be happy with this kind of functionalism. One can stay objectivist but still keep the independence of the trade. Furthermore, the psychologist can also entertain illusions that it is actually she or he who shall show the physiologist or the UFO expert what kind of material systems to look for. Namely, they should be ones that are in principle capable of realizing the given functions described by psychology.

Thus, the overview of the way psychology has been flirting with computers during the last 40 years brings up the following morals. Psychologists are inspired and disillusioned in machine thought in a cyclical way. At the end of the cycles, however, it comes out that the technological metaphor finally leads back to the basic philosophical questions. Classical issues become relevant again, and questions arise like is the human mind unitary or divided, is man a conglomeration of accidental habits or is the mind to be characterized rather by at least partially a priori given rules, what is the correct interpretation of the relationship between body and mind? We end up in a peculiar intellectual situation where the most technically minded excursions in contemporary psychology lead back to Plato, Aristotle, Descartes and the classical issues of epistemology and psychology in general. Thus the machine as technological metaphor has proven unable to succeed in ruling thought Polanyi would be glad to see that machine minded thought turns against itself towards a revitalization of classical issues in the humanities.

References

Allport, D.A. (1980). Patterns and actions: Cognitive mechanisms are content specific. In Claxton, G. L., ed. *Cognitive psychology: New directions.* London: Routledge and Kegan Paul, 112-153.

Anderson, J. R, and Bower, G.H. (1973). *Human associative memory.* Washington: Hemisphere

Baddeley, A. D. (1976). *The psychology of memory.* New York: Wiley.

Bartlett, F. (1932). *Remembering.* Cambridge: Cambridge University Press.

Block, N., ed., (1980). *Readings in the philosophy of psychology.* Vol. 1. Cambridge: Harvard University Press

Brink, J. R., and Haden, C. R., eds., (1989). *The computer and the brain: Perspectives on human and artificial intelligence.* **Amsterdam: North-Holland.**

Broadbent, D. (1958). *Perception and communication.* Oxford: Pergamon Press.

Bruner, J. (1957). On perceptual readiness. *Psychological Review,* 64, 123-152.

Changeux, J.-P. (1983). *L'homme neuronal.* Paris: Fayard.

Changeux J.-P. and Connes, A. (1989). *Matierc a pensee.* Paris: Jacob.

Chomsky, N. (1957). *Syntactic structures.* Hague: Mouton.

Chomsky, N. (1959). *A review of Skinner's Verbal Beliav'tor. Lanquage,* 35, 26-58.

Chomsky, N. (1965). *Aspects of a theory of syntax.* Cambridge: MIT Press.

Chomsky, N. (1968). *Language and mind.* New York: Harcourt.

Churchland, P. (1986). *Neurophilosophy.* Cambridge, Mass.: MIT Press.

Clark, A. (1989). *Microcognition.* Cambridge: MIT Press.

Collins, A. M. and Quilian, M. R. (1969). Retrieval time from semantic memory. /. *Verbal Learn. Verb. Beh.,* 8, 240-247.

Craik, F. I. M. and Lockhart, R. S. (1972). Levels of processing: A framework for memory research. *J. Verb. Learn. Verb. Behav.,* 11, 672-684.

Crosson, F. J. (1985). Psyche and the computer. In Koch, S. and Leary, D. E, eds. *A century of psychology as science.* New York: McGraw Hill, 437-451.

Danchin, A. (1980). Comment peut-on parler de l'automate cerebrale aujourd'hui? *Revue Philohique,* 105, 287-304.

Dehn, N., and Schank, R. (1982). Artificial and human intelligence. In Sternberg, R.J., ed. *Handbook of human intelligence.* Cambridge: Cambridge Univ. Press, 352-391.

Dennett, D. C. (1991). *Consciousness explained.* Boston: Little Brown.

Dreyfus, H. (1979). *What computers can't do: A critique of artificial intelligence.* 2nd. ed. San Francisco: Freeman.

Dreyfus, H. (1990). Socratic and Platonic sources of cognitivism. In Smith, J. G, ed., (1990). *Historical foundations of cognitive science.* Dodrecht: Kluwer, 1-17.

Edelman, G. M. (1987). *Neural Darwinism.* New York: Basic Books.

Fahlmann, S. E. (1988). Parallel processing in artificial intelligence. In Kowalik, J. S., ed. *Parallel computation and computers for artificial intelligence.* Boston: Kluwer, 3-19.

Feigenbaum, E. A., and Feldman, J., eds. (1963). *Computer and thought.* New York: McGraw Hill.

Feldman, J. A. and Ballard, D. H. (1982). Connectionist models and their properties. *Cognitive Science,* 6, 205-254.

Fodor, J. A. (1968). *Psychological explanation.* New York: Random House.

Fodor, J. A. (1975). *The language of thought.* Cambridge: Harvard University Press.

Fodor, J. (1981). *The mind-body problem.* Scientific American, 244(4), 124-132.

Fodor, J. A. (1983). *The modularity of mind.* Cambridge: MIT Press.

Fodor, J. A., Bever, T. G., and Garrett, M. F. (1974). *The psychology of language.* New York: McGraw-Hill.

Fodor, J., and Garrett, M. (1966): Some reflections on competence and performance. In Lyons, J. and Wales, R., eds. *Psychol inguistic papers.* Edinburgh: Edinburgh University Press, 135-154.

Fodor, J. A. and Pylyshyn, Z.W. (1988). Connectionism and cognitive architecture. *Cognition*, 28, 3-71.

Gardner. H. (1985). *The mind's new science: A history of the cognitive revolution.* New York: Basic Books .

Garfield, J., ed. (1987). Modularity in knowledge representation and natural language processing. Cambridge: MIT Press.

Graesser, A., and Black, J., eds. *The psycholopgy of questions.* Hillsdale: Erlbaum.

Harnad, S. (1990). The symbol grounding problem. *Physica D,* 42, 335-346.

Harnad, S. (1993). Foundations of cognition. Course given at Eotvos University, Budapest, 26-30 April, 1993.

Hebb, D. O. (1949). The organization of behavior. New York: Wiley.

Hinton, G. and Anderson, S., eds. (1981). *Parallel models of associative memory.* Hillsdale, N. J.: Erlbaum.

Hofstadter, D. (1987). Cognition, subcognition. *Le Debat,* 47, 26-44.

Hull, C. L. (1943). *Principles of behavior.* New York: Appleton.

Julesz B. (1984). Toward an axiomatic theory of preattentive vision. In Edelman, G. M, Cowan, W. M., and Gall, W. E., eds. *Dynamic aspects of neocortical functions.* New York, Basic Books, 585-612.

Kahnemann, D. (1973). *Attention and effort.* Englewood Cliffs: Prentice Hall.

Kowalik, J. S. ed., (1988). *Parallel computation and computers for artificial intelligence.* Boston: Kluwer.

Kripke, S. (1972). Naming and necessity. In Davidson, D. and Harman, G., eds. *Semantics and Natural language.* Dordrecht: Reidel.

Lachmann, R., Lachmann, J. L., and Butterfield, E. C. (1979). *Cognitive psychology and information processing.* Hillsdale, N. J.: Erlbaum.

Lachter, L. and Bever, T. G. (1988). The relation between linguistic structure and associative theories of language learning. *Cognition,* 28, 195-247.

Lycan, W. G., ed. *Mind and cognition. A reader.* Cambridge: Basil Blackwell.

McClelland, J. (1988). Connectionist models and psychological evidence. /. *of Memory and Language,* 27, 107-123.

Marr, D. (1982). *Vision.* San Francisco: Freeman.

McClelland, J. L., and Rumelhart, D. E. (1986). *Parallel distributed processing.* Vol. 2. Cambridge: MIT Press.

McCulloch, W. S., and Pitts, V. (1943). A logical calculus of the ideas immanent in nervous activity. *Bull. Math. Biophys., 5,* 45-133.

Mehler, J. and Dupoux, E. (1987). De la psychologie la science cognitive. *Le Debat,* 47, 65-87.

Miller, G. A., and Chomsky, N. (1963): Finitary models of language users. In Luce, R. D., Bush, R. R., Galanter, E., eds. *Handbook of mathematical psychology.* Vol. II. New York: Wiley, 419-491

Neisser, U. (1963). The multiplicity of thought. *British Journal of Psychology,* 54, 1-14.

Newell, A. (1990). *Unified theories of cognition.* Cambridge, Mass.: Harvard University Press.

Newell, A., and Simon, H. (1972). *Human problem solving.* Englewood Cliffs, N.J.: Prentice Hall .

Norman, D. A., ed. (1981). *Perspectives on cognitive science.* Hillsdale: Lawrence Erlbaum.

Nyiri, J. C. (1992). *Tradition and individuality.* Dordrecht: Kluwer.

Osgood, C. E. (1963). *On understanding and creating sentences.* Amer. Psychologist, 18, 735-751.

Pfeifer, R., Schreter, U., Fogelma-Souli, F., and Steels, L., eds. (1989). *Connectionism in perspective.* Amsterdam: North-Holland.

Pinker, S., and Mehler, J., eds. (1988). *Connections and symbols.* Cambridge: MIT Press.

Pinker, S. and Prince, A. (1988). On language and connectionism. *Cognition* 28 , 73-193.

Pleh, Cs. (1985). Brain language. On a book by Jerry A. Fodor. *Folia Linguistica,* 19, 539-548.

Pleh, Cs. (1987). On formal- and content-based models of story memory. In: Halasz, L., ed. *Literary discourse. Aspects of cognitive andsocial psychological approaches.* Berlin: de Gruyter, 1987, 100-112.

Pleh, Cs. (1992). The renaissance of association in contemporary cognitive psychology. *Acta Univ. Budapestiensis deLorande Eotvos Nom. Sectio Philosophica,* 24, 161-171.

Polanyi, M. (1962). *Personal knowledge.* London: Routledge & Kegan Paul.

Polanyi, M. (1967). Life transcending physics and chemistry. *Chemical and Engineering News,* 45, August, 54-66.

Polanyi, M. (1968). Logic and psychology. *American Psychologist,* 23, 27-43.

Polanyi, M. (1969). *Knowing and being.* Chicago: The University of Chicago Press.

Posner, M. I. (1986). *Chronometric explorations of mind.* Oxford: Oxford University Press.

Putnam, H. (1960). Minds and machines. In Hook, S., ed.

Dimensions of mind. London: Collier Books, 138-164.

Putnam, H. (1988). *Representation and reality.* Cambridge: MIT Press.

Pylyshyn, Z. W., (1972). Competence and psychological reality. *American Psychologist,* 27, 546-552

Pylyshyn, Z. W., (1984). *Computation and cognition.* Cambridge: MIT Press.

Rumelhart, D. E. (1980). Schemata. The building blocks of cognition. In Spiro, P., Bruce, B. and Brewer, W., eds. *Theoretical issues in reading comprehension.* Hillsdale: Erlbaum.

Rumelhart, D. E., and McClelland, J. L. (1986). *Parallel distributed processing.* Vol. 1. Cambridge: MIT Press

Rumelhart, D. E., and McClelland, J. L. (1987). Learning the past tenses of English verbs: Implicit rules or parallel distributed processing? In MacWhinney, B., ed. *Mechanisms of language acquisition.* Hillsdale: Erlbaum.

Ryle, G. (1949). *The concept of mind.* London: Hutchinson.

Schank, R. (1982). *Dynamic memory. A theory of reminding in computers and people.* Cambridge: Cambridge University Press.

Schank, R., and Abelson, R. (1977). *Scripts, plans, goals and understanding.* Hillsdale: Erlbaum.

Schiller, H. P. (1946). *Die Aufgabe der Psychologie.* Wien: Segal and Lachman, 1977.

Simon, H. (1979). *Models of thought.* New Haven: Yale University Press.

Smith, E. E., Shoben, E. J., and Ripps, L. J. (1974). Structure and process in semantic memory. *Psychol. Review,* 81, 214-241.

Smith, J. C, ed. (1990). *Historical foundations of cognitive science.* Dodrecht: Kluwer.

Smolensky, P. (1988). On the proper treatment of connectionism. *Behavioral and Brain Sciences,* 11, 1-23.

Szentagothai, J. (1975). The module-concept in cerebral cortex architecture. *Brain Research,* 95, 475-496.

Ujlaki, G. (1992). A hallgatolagos es az explicit tudas. Polanyi Mihaly poszt-kritikai filozofiaja. (Tacit and explicit knowledge. The postcritical philosophy of Mihaly Polanyi.) In *Polanyi Mihály filozofiai irásai* II. Budapest: Atlantisz, 276-328.

Watt, W. C. (1970). On two hypotheses concerning psycholinguistics. In Hayes, J. R., ed.: *Cognition and the development of language.* New York: Wiley, 137-220.

Wertheimer, M. (1922). Untersuchungen zur Lehre von der Gestalt. *Psychologische Forschung,* 1, 47ff.