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The Computational Metaphor and Cognitive Psychology

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Abstract
The past three decades have witnessed a remarkable growth of research interest in the mind. This trend has been acclaimed as the 'cognitive revolution' in psychology. At the heart of this revolution lies the claim that the mind is a computational system. The purpose of this paper is both to elucidate this claim and to evaluate its implications for cognitive psychology. The nature and scope of cognitive psychology and cognitive science are outlined, the principal assumptions underlying the information processing approach to cognition are summarised and the nature of artificial intelligence and its relationship to cognitive science are explored. The 'computational metaphor' of mind is examined and both the theoretical and methodological issues which it raises for cognitive psychology are considered. Finally, the nature and significance of 'connectionism'—the latest paradigm in cognitive science—are briefly reviewed.

Introduction

The remarkable upsurge of research interest in cognition has been acclaimed as a revolution in twentieth-century psychology (Baars, 1986; Gardner, 1985; Matlin, 1989). This revolution was hastened by three developments between 1940 and 1960 (Lachman et al., 1979). Firstly, it was shown that Behaviourism, the dominant paradigm in that era, was unable to explain how people understand and acquire language (Chomsky, 1959). Secondly, the development of Communication Theory (Shannon & Weaver, 1949) provided a method of measuring the amount of information flowing through a given system. Thirdly, the advent of digital computers offered psychologists both a plausible metaphor (i.e., the mind as a computational system) and a new method (i.e., computer simulation) for the investigation of the mind.

In this paper, we focus on the third of these developments. Our intention is to examine the principal psychological issues raised by the view that the mind is a computational system, what Boden (1979) called the 'computational metaphor'. We begin by sketching the nature of cognitive psychology and its interdisciplinary ally, cognitive science. We then outline the assumptions underlying the information processing paradigm in contemporary cognitive psychology. This is followed by an analysis of the nature of Artificial Intelligence (AI) and its relationship to cognitive science. We then articulate the computational metaphor and critically explore some significant issues which it raises for cognitive psychology. Finally, we examine Connectionism, (McClelland et al.. 1986; Rumelhart et al., 1986), the 'new wave' in cognitive science, and compare and contrast it with Classical Computationalism (Palmer, 1987).

Cognitive psychology and cognitive science

Cognitive psychology is the modern discipline which tries to elicit empirical answers to the venerable question of how the mind works. It is concerned with the acquisition, representation and use of human knowledge and it investigates the mental processes "by which the sensory input is transformed, reduced, elaborated, stored, recovered and used" (Neisser, 1967, pp. 4-5). According to Neisser, whose textbook is the seminal work in this field, "the task of ... trying to understand human cognition is analogous to that of ... trying to understand how a computer has been programmed" (p.6). This analogy is chosen because a computer program is a "recipe for selecting, storing, recovering, combining, outputting and generally manipulating information" (p.8). As the computer operates computationally, so too, it seems, does the human mind. This computational view of mind is the dominant metaphor in contemporary cognitive psychology (Matlin, 1989).

Cognitive science is the study of "systems for knowledge representation and information processing" (Shepard, 1988, p. 45). It is an interdisciplinary movement which includes cognitive psychology and artificial intelligence, linguistics, neuropsychology, and the philosophy of mind (Neisser, 1988).

Although many psychologists consider 'cognitive psychology' and 'cognitive science' to be equivalent, Claxton (1988) claimed that the disciplines differ in their research strategies. Whereas cognitive psychologists seek theories which may be tested by traditional experimental methods, cognitive scientists prefer theories which can be implemented as computer programs. Despite this alleged difference, both disciplines share the fundamental belief that cognition involves information processing (Best, 1986; Matlin, 1989; Solso, 1988). We shall therefore outline the principal assumptions of the information processing approach to cognition.

The information processing (IP) approach to cognition

The information processing (IP) paradigm currently dominates both cognitive psychology and cognitive science (Barber, 1988; Matlin, 1989; Reed, 1988; Solso, 1988). This approach (analysed in detail by Lachman et al., 1979) explores the mind "in terms of the integrated operation of fundamental processing mechanisms which act upon, and are themselves acted upon, by the flow of information through the system" (Williams et al., 1988, p. 14). It rests on a set of general assumptions, which are summarised in Table 1.

Table 1. Assumptions of the information processing approach to cognition.

1. The mind may be regarded as a *general purpose, symbol processing* (or 'computational') *system*.
2. Information is *represented symbolically* in the mind (Gardner, 1985).
3. Both the computer program and the mind may be regarded as carrying out a task in a series of *programmed steps*. Thus cognitive processes are assumed to occur as a "sequence of successively transformed states" (Hayes & Broadbent. 1988, p. 271). In other words, each step in the sequence changes its immediate predecessor.
4. Information processing analysis involves the tracing and *reduction of mental operations to component processes*. As Barber (1988) claimed, the information processing approach provides "a detailed analysis and specification of psychological activities in terms of component processes and procedures" (p. 19).
5. The information processing system is thought to be organised into *stages*. Barber (1988) claimed that "processing stages are ... components or modules contributing to the functioning of the overall system" (p. 19).
6. Cognitive processes *take time*. The duration and chronological sequence of such processing may reveal aspects of its nature and organisation (Lachman et al., 1979).
7. The mind is a *limited capacity* system (Atkinson & Shiffrin, 1968).

On the basis of these assumptions, it is clear that cognitive scientists "seek to study the representation of knowledge, the nature of the processes that operate on these representations, and the causal order among those processes" (Roitblatt, 1987, p. 5). Researchers who use the IP approach seek models of the ways in which people represent, process and use the knowledge in their minds.

It appears that the IP approach has some advantages. First, attempts to write programs that will mimic human cognition tend to reveal its full complexity. Because computational theories have to be precise and explicit, they highlight gaps and hidden assumptions in researchers' thinking. Second, the requirement that programs must work (e.g., solve a given problem) provides a guarantee that no steps have been ignored in the theory. A successful program overcomes the criterion of 'sufficiency', which demands that the steps in the program are sufficient for performing the appropriate cognitive activity. In general, it may be said that "models that actually run on real computers are more convincing than models that exist only as hypotheses on paper" (Neisser, 1985, p. 18).

Having explained the assumptions and advantages of the information processing ap\proach to cognition, let us now consider the nature of artificial intelligence and its relevance to psychology.

Artificial Intelligence

The term 'Artificial Intelligence' was introduced to the world by John McCarthy and Marvin Minsky at a conference, on the simulation of intelligent behaviour, in Dartmouth, New Hampshire, in 1956 (Gardner, 1985). Since then, Al has been variously characterised as part of computer science (Garnham, 1988), as an attempt to understand how representational structures can generate behaviour (Boden, 1988), as an effort to produce machines with minds (Haugeland, 1985) and as the study of ideas that enable computers to be intelligent (Winston, 1984). These accounts of Al are neither mutually exclusive nor universally exhaustive.

In general, there are two main objectives in Al research (Winston, 1984). The first is that of making computers more useful to people. The second is that of exploring the principles that make intelligence possible. Phrased differently, Al researchers with the former goal tend to be interested in developing intelligent *machines* whereas those with the latter aim seek to create *intelligent* machines.

According to Reeke & Edelman (1988). the typical Al research paradigm may be described as follows. Firstly, a problem is selected for study. Next, the items of information needed to solve this problem are identified. Thirdly, research is conducted on how this information might be represented best on computer. Then an algorithm is found to manipulate the information to solve the problem. Next, a computer program is written to implement this algorithm. Finally, the program is tested on sample instances of the problem. This approach has resulted in many impressive demonstrations in Al research. j For example, programs have been written to understand human language (e.g., MARGIE: Schank, 1975). Furthermore, 'expert' or knowledge-based systems have been developed. These systems are designed to provide software equivalents of expert, human consultants. Therefore, they provide 'advice' in situations where specialised knowledge and experience are required. In general, expert systems (e.g., MYCIN: Shortliffe, 1976) combine a knowledge-base of factual information about a domain (in this case, medical diagnosis) with an 'inference-engine' (for generating conclusions).

At this stage, however, we should clarify the sense(s) in which Al is relevant to psychology. To do so we will adopt Flanagan's (1984) taxonomy. He postulated four different kinds of Al. To begin with there is *nonpsychological* Al. Here, the Al worker builds and programs computers to do things that, if done by human beings, would require intelligence. No claims are made about the psychological realism of the programs. In *weak psychological Al*, the computer is regarded as being a useful tool for the study of the human mind. Programs simulate alleged psychological processes in human beings and allow researchers to test their predictions about how those' alleged processes work. This is the kind of Al that Russell (1984) took to be relevant to cognitive psychology. *Strong psychological Al* is the view that the computer is not merely an instrument for the study of mind but that it really is a mind. Finally, there is *suprapsychological Al*. This is at one with strong psychological Al in claiming that mentality can be realized in many different types of physical devices but goes beyond the anthropological chauvinism of strong psychological Al in being interested in all the conceivable ways that intelligence can be realized.

Of these four kinds of Al, only weak and strong Al are directly relevant to cognitive psychology, whereas cognitive science is additionally concerned with suprapsychological Al.

The relationship between Al and cognitive psychology/cognitive science

Al and cognitive psychology have. according to Solso (1988), "a kind of symbiotic relationship, each profiting from the development of the other" (p. 460). For example, cognitive psychology can guide Al in "the identification of cognitive structures and processes that can ultimately be implement as part of an AI-based model" (Polson et al., 1984, p. 280). Conversely, Al can provide "conceptual tools necessary to formalize assumptions about representation and process that are basic to all of the cognitive sciences" (Poison et al.. 1984, p. 290).

Stronger claims have been made about the relationship between Al and cognitive psychology than that which alleges a symbiosis between the disciplines (Allport, 1980; Boden, 1979, 1988; Mandler. 1984). Having suggested that Al can provide an integrative framework for the interpretation of research on cognition, Allport (1980) claimed that "the advent of Artificial Intelligence is the single most important development in the history of psychology" (p. 31). More recently. Mandler (1984) has suggested that "as keeper of the computational grail, the Al community may well turn out to be for the cognitive science what mathematics has been for all the sciences. If mathematics is the queen of the sciences, Al could earn the mantle of the Prince of Wales of the cognitive sciences" (p. 307). More prosaically. Glass et al. (1979) believed that whereas Al explores "the general question of how intelligent systems can operate. Cognitive Psychology deals with one particular intelligent system, the human being" (p. 44).

The computational metaphor

The growth of modem cognitive psychology has been hastened by the advent of the computer, the ability of which to store and transform symbolic information is in some ways akin to cognitive processing (Neisser, 1976). As the computer is, in essence, a computational machine, cognitive psychology and cognitive science, in adopting the computer as their central model, have taken the computational metaphor to heart. The metaphor may be expressed thus: the mind is governed by programs or sets of rules analogous to those which govern computers. A computer is a physical symbol system and, as such, it belongs to "a broad class of systems capable of having and manipulating symbols, yet realizable in the physical universe" (Newell, 1980, p. 135).

Computational psychologists are "theorists who draw on the concepts of computer science in formulating theories about what the mind is and how it works" (Boden, 1988, p. 225). Thus they are interested in exploring similarities and differences between the information processing activities of people and those of computers.

The basic characteristics of computational psychology were expressed by Boden (1988) as follows: to begin with, mental processes may be defined functionally "in terms of their causal role (with respect to other mental states and observable behaviour)" (p. 5). Moreover, such processes are "assumed to be generated by *some effective procedure*" (p. 5), or precisely specified set of instructions within the mind. Next, the mind is regarded as a representational system. Therefore, psychology is considered to be "the study of the various computational processes whereby mental representations are constructed, organised, interpreted and transformed" (p. 5). (Note that 'computation' refers to rule-governed symbol manipulation). Finally, if cognitive science pays any attention to neuroscience, it is more concerned with what the brain is doing and how it works, than with what it is made of. Thus it explore the issue of "what the brain does that enables it embody the mind" (p. 6).

The advantages of the computational metaphor

The value of the computational metaphor of mind has been highlighted by Allport (1980), Boden (1979,1988) and Sloboda (1986). At least two classes of advantage — theoretical and methodological — are usually adduced in support of the computational metaphor in cognitive psychology. These may be summarised as follows:

Theoretically, the computational metaphor of cognition is advantageous "because its conceptual focus is on representation and processes of symbolic transformation" (Boden. 1988, p. 6). Clearly, as Table 1 indicates, this emphasis suggests that Al explicitly endorses the information processing approach to the mind. Furthermore, as Boden (1979) proposed, the concept of programs regulating behaviour may enable us "to understand how it is possible for the immaterial mind and the material body to be closely related" (P.111).

Methodologically, many authors (e.g., Boden, 1979,1988; Mandler, 1984) have concluded that the computational approach can serve as a useful tool for testing psychological theories. Thus "the intellectual discipline required to produce a program which actually works is a valuable aid to better theorising" (Sloboda, 1986, p. 201). This occurs because the attempt to specify explicit instructions for a program in a given domain tends to illuminate vague, biased, incomplete or inconsistent thinking which often remains undetected in verbally-stated theories. Secondly, the method of computer modelling "offers a manageable way of representing complexity, since the computational power of a computer can be used to infer the implications of a program where the unassisted mind is unable to do so" (Boden, 1988, pp. 6-7). Thus, the computer may help psychologists to simplify and understand computationally complex implications of theories. Thirdly, Claxton (1988) has acknowledged the value of the 'computational criterion' (i.e., the degree to which a theory can be implemented successfully as a simulation of a given psychological process or aspect of behaviour) in evaluating psychological theories. In general, theories which are coherent may be implemented computationally.

Critical evaluation of the computational metaphor

Despite its current popularity and heuristic value, reservations have been expressed by researchers in cognitive science as to the ultimate value of the computational metaphor for psychology. We shall consider reservations based on apparent dissimilarities between brain and computer, methodological reservations, and theoretical reservations.

Brain and computer.

The cornerstone of the traditional computational approach in cognitive science is the 'physical symbol system' hypothesis (Newell & Simon. 1972). This hypothesis proposes both that symbols (i.e., word-like or numerical entities) are the primitive components of the mind (Waltz, 1988) and that humans and computers are members of a larger class of information processing systems (McCorduck, 1988). The key assumption of this view is the alleged similarity between the brain and a computer. How valid is this analogy?

To begin with, several strands of evidence combine to suggest that the digital computer is an inadequate model of the brain. For example, whereas such a computer processes information serially, the brain is known to work in parallel fashion (Pinker & Prince, 1988). In addition, although the brain operates slower than the computer, the brain is "far more adaptable, tolerant of errors and context-sensitive" (Kline, 1988, p. 85; see also Ornstein, 1986). Furthermore, even the most sophisticated supercomputer developed to date "seems unlikely to achieve more than 1 percent of the brain's storage capacity" (Schwartz, 1988, p. 127). In summary, these criticisms erode the validity of the analogy between the brain and the digital computer. However, they may not apply to connectionist models (to be discussed later) which place great emphasis on parallel processing activities.

Perhaps the most damaging criticism of any analogy between brain and computer, however, is that which concerns *bodily* knowledge. Briefly, the brain cannot be investigated adequately in isolation from the body of which it is an integral part. If the role of bodily knowledge is ignored, computational psychologists are in danger of developing 'academiomimesis', a 'disorder' characterised by the delusion that mind consists only of verbal and logical processes (Ornstein, 1986, p. 20). Indeed, in accepting the view that people are only physical symbol systems we are in danger of concluding that they are pure intellects (Norman, 1980, p. 4). It is not surprising, then, that many cognitive models "seem to be theories of pure reason" (Norman, 1980, p. 11). This exaggerated rationalism is a legacy from Descartes who was the first modem philosopher to postulate a radical separation of mind from body (Descartes, 1911). If human beings are pure intellects then their knowledge is purely intellectual and the human body need not be taken into account in a theory of cognition. This assumption of computational psychology has been criticised by Papert (1988) who believes that "we have much more to learn from studying the difference, rather than the sameness, of different kinds of knowing" (p. 2).

In a similar vein, Claxton (1988) reminded us that whereas human cognition grows ontogenetically "on the basis of a vast amount of (mostly non-verbal) experience, 'the computer's knowledge' arrives codified, ready-made and relatively fixed" (p. 14). Over-emphasis on the rule-governed aspects of cognition may blind us to the fact that much contemporary research suggests that "human thought emerges as messy, intuitive, subject to subjective representations—not as pure and immaculate calculation" (Gardner, 1985, p. 386). Interestingly, connectionist models of the mind, as distinct from traditional computational counterparts, begin with, rather than avoid, the 'fuzziness' of human cognition.

In practice, however, the preference of computational psychologists (whether classical or connectionist) for nomothetic theoretical explanations has led to a neglect of such important topics as the nature of individual differences and the role of emotions and motivation in cognition (Norman, 1980). However, it should be noted that recent research on emotional disorders suggests that emotional and motivational influences on behaviour can be studied fruitfully from the perspective of computational psychology (Brewin, 1988; Williams et al., 1988).

Methodological reservations.

The metaphor of computation sometimes seems to be taken literally. As Turbayne (1970) reminded us "there is a difference between using a metaphor and taking it literally, between using a model and mistaking it for the thing modelled" (p. 3). An example of the literal interpretation of the computational metaphor is evident in the claim that "the mind is physically built out of neurons" (Roitblatt, 1987, p. 10). Clearly, such a literal interpretation increases the possibility of simplistic experimentation.

In general, the computational metaphor generates enquiries with restricted scope. Clearly, the crucial issue here is whether or not the methods adopted in such enquiries are adequate to tackle the phenomena in question. For example, even if it be granted that computational psychology can account for rule-governed cognitive activity, the question may still be asked as to whether or not this can be adequately extrapolated to all of cognition—including the 'fuzzy' domain (Claxton, 1988; Gardner, 1985; Haugeland, 1985; Westcott, 1987). Because of the artificial restrictions on the domain of study in cognitive science, the *psychology* in cognitive science tends to get short shrift. Indeed, Best (1986) warned us of the danger of cognitive psychology's being put out of business by premature absorption into cognitive science (p. 499). The overall tendency in cognitive science is, if one may so phrase it, to remove cognition from its natural human setting in order to study it in the abstract. The problem is, that once the abstraction has been effected, it is difficult to see how the findings of cognitive science are to be applied to the concrete world of psychology. Of course, this is not just a problem for computational psychology. It is a recurrent difficulty for all empirical approaches within the discipline. However, it is particularly troublesome for researchers in the fields of language comprehension and problem solving. For example, according to Dreyfus (1986), little progress has been made in the attempt to generalise to real-life settings from results obtained in artificial 'micro-worlds' (as found, for example, in Winograd's, 1972, SHRDLU program). Similarly, little success is evident in researchers' attempts to simulate the ways in which people solve the ill-defined problems (i.e., those in which initial and/or goal states are equivocal) of everyday life. Perhaps this reflects the fact that protocols are easier to gather, and simulations easier to write, for well-defined tasks, such as chess-playing and theorem-proving. This suggests that simulation research is method-driven rather than topic-driven.

Another methodological issue concerns the *equivalence* of a computer simulation to that which it is alleged to simulate. Matlin (1989) pointed out that human goals tend to be complex and fluid. Therefore, in the attempt to simulate the behaviour of chess-players, for example, researchers should realise that people playing a game of chess may be concerned about "how long the game lasts, about their social obligations, and about interpersonal interactions with their opponents" (p. 10). Accordingly, simulations which fail to represent these phenomena may be spurious. In a similar vein, the alleged precision of simulations may be challenged. In particular, it is well known that simulation programs often incorporate "little decisions — just to get our program to run that are irrelevant to our main concerns, and often psychologically uninteresting" (Claxton, 1988, p. 14). Such ad hoc programming decisions undermine the precision of the resulting simulation.

Yet another methodological issue is raised by the possibility that an apparently plausible simulation of behaviour may beguile us into believing that we have discovered how the mind works in a given area. Obviously, even if one succeeds in simulating intelligent behaviour on a computer, it does not necessarily follow that the process(es) by which that behaviour was produced is (or are) identical to, or even significantly similar to, the process(es) that produced the human behaviour (Bell & Staines, 1981). Indeed, Papert (1988) warned against the category error of assuming that "the existence of a common mechanism provides an explanation for both mind and machine" (p. 2) in any domain.

Overall, then, the suspicion lingers that theory in computational psychology is merely an externalisation of intuitions (Kline, 1988). Clearly, we must distinguish between the articulation of intuitions and the production of an explanatory theory. In the *articulation of intuitions*, a phase that usually precedes explanation, the elements of the articulated intuition are not independently verified. Explanation, by contrast to intuitive articulation, involves a necessary commitment (at least in principle) to an objective criterion of confirmation or refutation.

Theoretical Reservations.

Apart from the preceding methodological reservations, can computational psychology, in principle, explain the higher mental processes? The heart of the problem seems to reside in the computational psychologists' *identification* of mental processes with computation (Boden, 1988, p. 229). This identification has an ancient philosophical lineage, its protoancestor being Thomas Hobbes, who claimed that "REASON ... is nothing but *reckoning*" (Molesworth, 1839b, p. 30) and "By RATIOCINATION, I mean *computation*" (Molesworth, 1839a, p. 3). It is interesting to note the similarity between Hobbes' 'brain-tokens' and Newell & Simon's (1972) 'physical symbols' hypothesis. As Haugeland (1985) pointed out, according to Hobbes, thinking consists of symbolic operations in which thoughts are not spoken or written symbols but special brain tokens.

We can see, then, that the central assumptions of cognitive science (see Table 1) are essentially the same as Hobbes' pronouncements on reason. In particular, according to Pinker & Mehler (1988), the central assumption of cognitive science is that "intelligence is the result of the manipulation of structured symbolic expressions" (p. 1; cf. Pinker & Prince, 1988, p. 74). Similarly, Haugeland (1985) stated that "cognitive science rests on a profound and distinctive *empirical* hypothesis: that all intelligence, human or otherwise, is realised in rational, quasi-linguistic symbol manipulation" (pp. 249-50), and Boden (1988) claimed that computational psychology "covers those theories which hold that mental processes are ... the sorts of formal computation that are studied in traditional computer science and symbolic logic" (p. 229).

However, there is a fundamental difficulty with this most basic assumption of the IP approach to cognition, a difficulty which was pithily expressed by Haugeland (1985), "Hobbes ... cannot tell the difference between minds and books. This is the tip of an enormous iceberg that deserves close attention, for it is profoundly relevant to the eventual plausibility of Artificial Intelligence. The basic question is: How can thought parcels *mean* anything?" (p. 25). Haugeland called this difficulty 'the mystery of original meaning', the point of this phrase being that once meaning enters a system it can be processed in various ways but the crucial problem is how it got into the system in the first place? Hobbes and his latter-day computational disciples appear to have had no answer to this question. Haugeland (1985) devoted a lot of space in his book to this topic but he was ultimately unable to come to a satisfactory resolution.

An essentially similar point has been made by John Searle (1980) in his widely-cited 'Chinese Room' thought experiment. Briefly, Searle asked us to imagine sitting alone in a room with a basket which contains a collection of Chinese symbols. If one had a rule-book in English which explained how to manipulate these symbols, one could *appear* to be capable of answering questions in Chinese, posed from outside the room, despite the fact that one could not understand Chinese. The point of this story is to show that from the perspective of an outsider (e.g., programmer), one's behaviour would give the impression that one understood Chinese (a successful simulation), but it would not be a correct impression. In other words, a system can have input and output capacities which duplicate those of a native Chinese speaker still not understand Chinese. What is lost in the AI simulation of language comprehension, according to Searle (1980), is the vital distinction between syntax (shuffling the Chinese symbols according to given rules) and semantics (knowing what the symbols mean). Therefore, Searle concluded that such simulations of mental phenomena are superficial and naïve.

Unlike other critics of the computational model, however, Searle (1980) was willing to allow that machines can encompass the feat of generating original meaning, but only if they are *biological machines*! It is only fair to point out that controversy rages in the philosophical journals on the merits and demerits of Searle's thought experiment, and gallant attempts have been, and are being made, to show how non-biological physical symbol systems can embody intentionality (Anderson, 1987; Brand, 1982; Bynum, 1985; Carleton, 1984; Lind, 1986; Maloney, 1987).

A related difficulty arises in connection with the key notion of 'information'. Boden (1988) asked "But what is 'information'? Doesn't it have something to do with meaning, and with understanding? Can a computer mean, or understand — or even represent —

anything at all?" (p. 225). Westcott (1987) claimed that "psychologists forgot that the notion of 'information' as developed by Shannon ... was absolutely meaningless. Information is merely a measure of channel capacity, admittedly important to communications theory; but 'information' bears no significance other than its occupancy of this channel capacity" (p. 283; p. 287). Similarly, Bakan (1980) claimed that "*the defect of the scientific universe of discourse is that it has no place in the objective world for information, except information in the bound* [i.e., materially embodied] *condition*" (p. 18, italics in original).

If Fodor (1980) is to be believed, the prospects for scientific psychology are bleak. He held that "computational psychology is the only theoretical psychology we can ever hope to achieve" yet "it is in principle incapable of addressing what many would regard as the prime question of psychology: how symbolic processes guide our perception of and action in the world" (Fodor 1980, cited in Boden 1988, p. 232). It follows from the very nature of computational psychology that "it can view mental processes only as operations within an *uninterpreted* formal system" (Boden, 1988, p. 232) and, as such, computational theories "cannot have anything to say about how mental states map onto the world" (p.233). "Computational psychology", said Fodor, "is committed to 'methodological solipsism'" so that "there is no point in trying to discover any mappings between the mind and the world, because for the purposes of psychological research *how the world is makes no difference to one's mental states*" (p. 233).

Does cognitive science constitute a revolutionary new approach to the study of human beings? Not according to Westcott (1987). It was his opinion that there has been no revolutionary transition from behaviourism to cognitivism; rather, there has been a change in terminology coinciding with a stable and unchanging ideology. "Human cognition has not yet been taken seriously as a human function which arises on the base of human powers for agency and for dialectical thinking" (p. 281). The computer has simply been substituted for the rat, the pigeon and dog as the laboratory subject of choice. Westcott (1987) quoted approvingly Haugeland's (1985) suggestion that cognitive science might be 'an impostor paradigm'. An impostor paradigm is "an outlook and methodology adequate to one domain parading as adequate in quite another, where it has no credentials whatever. Cognitivism is behaviorism's natural child. It retains the same deep commitment to objective experiments, mechanistic accounts, and the ideal of 'scientific' psychology" (Haugeland, 1985. p. 252).

Connectionism (Parallel Distributed Processing): A new paradigm?

Connectionism, also known as Parallel Distributed Processing (PDP) or neural networks, is the new wave in cognitive science. It is claimed that this approach, especially as exemplified in the works of James McClelland and David Rumelhart is "a new paradigm for how to theorize about the mind, the brain, and the relation between them" (Palmer, 1987, p. 925; see also Schneider, 1987). "Almost everyone who is discontent with contemporary cognitive psychology and current 'information processing' models of the mind has rushed to embrace 'the Connectionist alternative'" (Fodor & Pylyshyn, 1988, p. 2). Connectionism is said to pose a challenge to the current computational model, a challenge of such magnitude that "what these theorists [i.e., McClelland and Rumelhart] are proposing is a theoretical challenge of the sort that occurred in physics when classical mechanics was displaced by quantum mechanics" (Palmer, 1987, p. 925). This new approach challenges the current computational assumption that mental processes can be represented and modelled as serial computer programs. Instead, it proposes that the mind is best understood in terms of massive, dynamic networks of interconnected units which resemble neurons. Whereas the conventional computational model would represent a concept as a single node, connectionists regard it as a pattern of activation distributed over a neural network. Each unit in the network receives signals from the other units and at any time it has a certain level of activation. The precise level of activation depends on the weighted sum of the states of activation of the units with which it is connected. Learning occurs when the weights (strength of connections) are adjusted in accordance with rules derived from environmental influences.

The revolutionary aspects of this approach are threefold. Firstly, it can account for "intelligent behaviour without storing, retrieving, or otherwise operating on structured symbolic expressions" (Fodor & Pylyshyn, 1988, p. 5). Secondly, the computer metaphor of mind seems to have supplanted by a neurological metaphor of mind. Thirdly, connectionist model of the mind differ radically from their symbolic predecessors in regard to the assumption of decomposability of mental processes. Whereas the conventional computational models have sought to decompose cognitive tasks into rules for manipulating representations, PDP systems explain rule-like behaviour as an emergent product of excitations and inhibitions between unit (Bechtel. 1988).

Adopting Fodor and Pylyshyn's (1988) terminology, and referring to the standard model in cognitive science as 'Classical', we may distinguish between the Classical model and the Connectionist model (see Table 2).

Table 2. Contrasting approaches of the Classical and Connectionist models of mind.

Classical Model	**Connectionist Model**
Mental processes modelled as programs running on a digital computer (Palmer 1987. p. 5)	Mental processes modelled as large-scale dynamic networks of simple, neuron-like processing units (Palmer 1987. p. 5)
Systems operate on structured symbolic expressions (Fodor & Pylyshyn, 1988, pp. 5-6)	Systems exhibit intelligent behaviour without storing, retrieving, or otherwise operating on structured symbolic expressions (Fodor & Pylyshyn, 1988, pp. 5-6)
Intelligence is the result of the manipulation of structured symbolic expressions (Pinker & Mehler. 1988, p. 1)	Intelligence is the result of the transmission of activation levels in large networks of densely interconnected simple units (Pinker & Mehler. 1988, p. 1)
The cognitive system decomposes cognitive tasks into rules for manipulating representation (Bechtel, 1988, p. 109)	Cognitive tasks are not decomposable into component cognitive operations (Bechtel, 1988, p. 109)

Palmer (1987) claimed that the Connectionist models are interesting to psychologists because they have emergent properties "which conform to certain properties of human cognition that are as elusive as they are pervasive; context addressable memory, automatic stimulus generalization, schematic completion of patterns and 'graceful degradation' of performance under average conditions" (p. 926).

As with the Classical model, reservations have also been expressed about the adequacy of the new Connectionist model. Palmer (1987) asked whether "the capabilities of PDP theories [will] ultimately prove sufficient to account for the range and power of the human mind?" (p. 927). Can network models be constructed to perform cognitive tasks in the same way that people do? Fodor and Pylyshyn (1988) concluded that when the argumentative dust has settled, the Classical approach still remains in position. "Discussions of the relative merits of the two architectures have thus far been marked by a variety of confusions and irrelevancies. It's our view that when you clear away these misconceptions what's left is a real disagreement about the nature of mental processes and mental representations. But it seems to us that it is a matter that was substantially put to rest about thirty years ago; and the arguments that then appeared to militate decisively in favor of the Classical view appear to us to do so still" (p. 6).

Would the Connectionist approach to cognitive science, if valid, escape the force of the preceding reservations? We think not, for even if Fodor and Pylyshyn's (1988) conclusion is not the only one possible, it still seems that, despite obvious differences between the Classical and the Connectionist approaches, they both appear to be forms of computationalism, albeit different forms. The classical computational architecture resembles Hobbesian ratiocination and the PDP approach seems like Lockean associationism. Indeed, Palmer (1987) referred to the Classical and Connectionist approaches as "these two computational paradigms" (p. 927).

Conclusion

In this paper, we have offered brief characterisations of cognitive psychology and cognitive science, sketched the IP approach to cognition common to them both, and related them to Al. We articulated the computational metaphor, outlined its advantages, and expressed our reservations about it in some detail. We concluded with a sketch of the recent Connectionist paradigm.

Although over half the paper has expressed reservations in respect of the computational metaphor, we do not propose these criticisms in a Luddite spirit. The IP approach to cognition, with its accompanying computational metaphor, has stimulated some of the most interesting research in psychology in recent years. Even if it were finally to be found wanting (and there is as yet no overall consensus as to its ultimate value) it would, nonetheless, have advanced our knowledge of human cognition beyond its previous limits. There is still the embryonic Connectionist (PDP) paradigm to be investigated and who knows what time, ingenuity, and effort will eventually bring to birth from it?

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