Cognitive Science and Psychology

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SYNOPSIS

The *protocol algorithm* abstracted from a human cognizer's own narrative in the course of doing a cognitive task is an explanation of the corresponding mental activity in Pylyshyn's *(1984) virtual machine model* of mind. Strong equivalence between an *analytic algorithm* and the *protocol algorithm* is an index of validity of the explanatory model. Cognitive psychologists may not find the index *strong equivalence* useful as a means to ensure that a theory is not circular because (a) research data are also used as foundation data, (b) there is no justification for the relationship between a to-be-validated theory and its criterion of validity, and (c) foundation data, validation criterion and to-be-validated theory are not independent in cognitive science. There is also the difficulty with not knowing what *psychological primitives* are.

Key Words

Sufficiency, Strong Equivalence, Analytic Algorithm, Protocol, Protocol Algorithm, Circularity

INTRODUCTION

The success of cognitive science is impressive at the formal level, as may be witnessed by the fact that a task like playing chess can readily be represented in the form of a computer program. Moreover, the result of implementing the program is very like that produced by a human expert. The achievement of cognitive science at the formal and implementation levels may be responsible for its being readily accepted by some psychologists.

Central to cognitive science is the practice of testing theories, or models, of mental phenomena with computer simulation. The *sufficiency* and *strong equivalence* criteria are used to validate results of computer simulation studies. The validity of this methodology is predicated on Newell and Simon's *(1972) sufficiency* and Pylyshyn's *(1984) strong equivalence* criteria. At the same time, underlying these criteria is a metatheoretical perspective. Hence, to accept cognitive science is to accept its meta-theoretical assumptions and theory-testing methodology. An examination of Pylyshyn's (1984) account of the foundation of cognitive science is instructive as to whether or not cognitive science is helpful to psychologists, particularly cognitive psychologists who study mental phenomena experimentally. This discussion begins with a synopsis of Pylyshyn's (1984) computational account of mind.

THE *VIRTUAL MACHINE* **MODEL OF MIND**

To Pylyshyn (1984), the human mind is a virtual computation machine whose functional architecture is made up of (a) a physical structure (viz., the brain), and (b) an operating system coded in a canonical language (e.g., Fodor's, 1975, *mentalese* or language of thought). The mentalese of speakers of a natural language, *L,* is an ontologically real, albeit unobservable, analog of *L.* The best way to think of a mentalese is to recall what is said about our linguistic competence in Chomsky's (1957) transformation grammar.

What may be included in the mentalese are (a) recursive phrase-structure rules (e.g., S -> NP + VP), (b) transformation rules (e.g., applying a passive transformation to a predicate in mentalese results in an assertion which would be a passive sentence in *L), (c) primitive operations,* or *primitives* (e.g., the truth rules in Fodor's, 1975, language of thought), (d) non-standard rules of inference whose function is to reduce the demands on the central processor by increasing the burden of the long-term memory store (e.g., the *meaning postulates* which "do the work that definitions have usually been supposed to do" [Fodor, 1975, p. 149]), and (e) a vocabulary as extensive as that of L (Fodor, 1975). In short, a theory of mind in cognitive science is a specification of the functional architecture of the virtual computation machine. While the physical structure constrains the memory resources and computation efficiency of the mind, this functional architecture determines the types of mental algorithms possible, as well as how they are actually being implemented. This model will subsequently be called the virtual machine model.

The contents of the mind are propositional representations of knowledge and algorithms. To engage in a mental or cognitive activity is to implement an algorithm coded in mentalese. In the course of such an activity, the mind's functional architecture undergoes changes from one knowledge-state to another knowledge-state in a rule-governed, or principled, manner. The success of the virtual machine model of mind depends on choosing an adequate set of primitives at the appropriate level of abstraction. Pylyshyn (1984) suggested the following meta-theoretical and methodological criteria for determining what primitives are admissible for inclusion in the virtual machine:

(1) A primitive must not be decomposable into more elementary units.
(2) It must be possible to maximize behavioral regularities at the level of intentional or rule-governed behaviors in terms of the primitives.
(3) Primitives should be cognitively inpenetratable in the sense that their status or the nature of their operations is not affected by changes in the input.
(4) Primitives must be realizable on a computer.
(5) A judicious combination of some primitives in a particular temporal order should be sufficient to explain how a cognitive task is being carried out.
(6) There must be empirical support for the primitives.
(7) The strong equivalence between a computer program and its counterpart in the human mind should be expressible in terms of the primitives.

Criteria (5), (6) and (7) may be used to illustrate some difficulties for psychologists if they adopt the meta-theoretical assumptions and methodology of cognitive science.

THE *SUFFICIENCY* **CRITERION**

In terms of the *virtual machine model,* a computer program coded to do Task A is considered a model for the cognitive activity undertaken by a human cognizer doing Task A. Hence, to explain a human cognitive activity is to show how a computer program may bring about the same result when the computer is provided with the same input. To assess whether or not a program is a good model is to show that the program is *sufficient* to complete Task A. This is Newell and Simon's (1972) *sufficiency* criterion or Pylyshyn's (1984) idea of *constructivism. Wear equivalence* is achieved between a program and a mental activity when the *sufficiency* criterion is satisfied (Pylyshyn, 1984).

A *sufficient* program, however, may only be a first approximation to an explanatory model of a mental activity (Newell & Simon, 1972). This is the case because, by itself, *sufficiency* is only the necessary criterion for a program's being an explanatory account for three reasons. First, more than one *sufficient* program may be able to mimic the observable, to-be-explained input-output regularity. Hence, *sufficiency* cannot be used to choose among competing programs *qua* explanatory models. Second, there may be two or more competing *sufficient* programs implicating different algorithms devised to be implemented on different virtual machines with unequal memory resources, different "mentaleses" and diverse modes of algorithm implementation. Third, a *sufficient* program may be circular because it is coded for the specific purpose of accounting for only the to-be-explained cognitive task and nothing else.

THE *STRONG EQUIVALENCE* **CRITERION**

The validity of a theory in cognitive science is established with the *strong equivalence* criterion. A computer program for Task A qua an explanatory model and how a human cognizer actually carries out Task A are equivalent in the strong sense when it can be shown that " ..the model and the organism are carrying out the same process..." (Pylyshyn. 1984, p. xv). Consider the task involved in generating the numbers from 0 through 9 such that each of the 10 numbers occurs 10 times in a random order in the 100-number list. This task may be done by a program coded in BASIC run on a Macintosh or in PASCAL run on an IBM PC. At the level of these two high-level languages, comparing these two programs is like comparing an apple to an orange. However, these two programs may actually be different realizations of the same algorithm at the level of the virtual machine. Pylyshyn (1978, 1984) suggests that these two programs are equivalent in the strong sense if it can be shown that they implicate the same set of primitives arranged in the same manner at the theoretical level if they are run on the same virtual machine. However, how a virtual machine program coded to handle Task A may be equivalent in the strong sense to how a human mind is used to deal with Task A is not made explicit in the virtual machine model. How do we ascertain strong equivalence between a program and a mental operation?

To deal with this issue, a cognitive psychologist may do something like what follows. An appropriate set of primitives of the virtual machine is first arranged in a theoretically determined order. That is, a theoretically determined algorithm is first determined for the virtual computation machine. The next step is to see whether or not the same algorithm can be expressed in terms of psychological primitives. However, this strategy raises the following questions: What are the psychological primitives? What theoretical properties do they have? How may these theoretical properties be ascertained at the empirical level? The virtual machine model is mute on these questions. Nonetheless, cognitive psychologists have to answer these questions.

PROTOCOL ANALYSIS

Leaving aside the difficulties with the concept of psychological primitives for cognitive psychologists, there is still the question as to how to ascertain that the program behaves in the same way as a human cognizer. Cognitive scientists appeal to Newell and Simon's (1972) protocol analysis (e.g., Pylyshyn, 1984; Stillings, Feinstein, Garfield, Rissland, Rosenbaum, Weisler & Baker-Ward, 1987). This methodology may be illustrated with a cryptarithmetic problem.

An individual given a cryptarithmetic problem is asked to assign the correct numbers to the letters in the following equation: **DONALD + GERALD = ROBERT.** A research participant solving a cryptarithmetic problem in Newell and Simon's (1972) study was required to "think aloud" as he solved the equation. The protocol of a participant's problem-solving attempt was made up of (a) the participant's verbalizations during the course of solving the problem, (b) what the participant actually wrote down, (c) remarks made by the researcher, and (d) "...additional data, about either the subject or the environment, that bears on the total performance" (Newell & Simon, 1972, p. 163).

Of particular importance to cognitive science is the idea that, as an individual engages in a cognitive task, the knowledge-state of the individual's functional architecture changes in a rule-governed way. Hence, Newell and Simon (1972) first worked out a sufficient algorithm on analytic grounds (subsequently called the analytic algorithm) for solving the cryptarithmetic problem. That is, as a ratiocination exercise, they construct a sequence of specific cognitive processes necessary to perform the task before giving it to any participant. They made explicit the entire sequence of changes in the virtual machine's knowledge-state as the analytic algorithm was being implemented.

Newell and Simon (1972) then abstracted from a participant's protocol the algorithm used when solving the cryptarithmetic problem (subsequently called the protocol algorithm). That is, participants were asked to describe what they were thinking as they performed the task. This running commentary was recorded verbatim. Newell and Simon abstracted from a human cognizer's verbal report an account of what the cognizer's knowledge-state was like at various theoretically determined stages in the course of carrying out a cognitive task. The *protocol algorithm* was then compared to the *analytic algorithm.*

Validity of protocol analysis

Before accepting the validity of protocol analysis as a means to reveal changes in a human cognizer's knowledge-state, cognitive psychologists need to ask the following questions:

(1) Are participants in circumstances like Newell and Simon's (1972) cryptarithmetic task situation really aware of their knowledge-states?

(2) Are the participants capable of distinguishing among the various knowledge-states implicated in a cryptarithmetic task (as well as identifying their order of occurrence)?

(3) Is a participant's verbal report a literal description of the participant's actual knowledge-state?

(4) How can a researcher be sure that such a narrative report is not the result of the participant's rationalization?

(5) How reliable is protocol analysis when its utility depends on the articulateness of the research participants?

Anticipating criticisms along the line of these questions, Newell and Simon (1972) declared, "...we are not treating these protocols as introspections" (p. 184). They defended their declaration by saying:

> The protocol is a record of the subject's ongoing behavior, and an utterance at time t is taken to indicate knowledge or operation at time t . ... Nor, in the thinking-aloud protocol, is the subject asked to theorize about his own behavior - only to report the information and intentions that are within his current sphere of conscious awareness. All theorizing about the causes and consequences of the subject's knowledge state is carried out and validated by the experimenters, not by the subject. (Newell & Simon, 1972, p. 184)

This justification for the validity of protocol analysis is debatable. The mere fact that a researcher does not treat research participants' narrative data as introspection is no guarantee that these narrative reports are not descriptive accounts of introspection (Pylyshyn, 1984).

Moreover, that a researcher does not ask the participants to theorize about their behavior does not mean that the participants would (or could) refrain from theorizing about what they are doing. There are good reasons to suggest that narrative data are unavoidably the result of a participant's theorization when the individual is forced to give a running commentary on something the individual may not be aware of. In other words, whatever is within a participant's "current sphere of conscious awareness" (Newell & Simon, 1972, p. 184) is likely the result of the participant's interpretation, rationalization or theorization.

To appreciate the third reason for questioning the validity of protocol analysis, it is necessary to recall that cognitive scientists use a participant's protocol as raw data to draw inferences about some unobservable mental events. Suppose that raw data are collected to test Theory T. These raw data should be atheoretical, or neutral, with reference to Theory T (Feigl, 1970; Chow, 1987). Raw data used to test Theory T should definitely not be contaminated by Theory T. This is not the case with Newell and Simon's (1972) treatment of their participants' protocols.

The fourth reason is that research participants in Newell and Simon's (1972) cryptarithmetic task are required to behave in an atypical way when they are asked to "think aloud" while carrying out a cognitive task. More specifically, the participants are (a) made self-conscious, (b) required to be articulate, and (c) induced to proceed more slowly or in a more deliberate way. In sum, the objectivity, reliability, validity and generality of protocol analysis as a theory-testing tool are debatable. Hence, it is not clear how useful the *strong equivalence* criterion is to psychologists in their investigation of the structural properties of the mind.

What to do when *strong equivalence* is not found?

Given the important role played by protocol analysis in the *strong equivalence* criterion, there is a further problem confronting psychologists. On the one side of the *strong equivalence* equation is the *analytic algorithm.* On the other side of the equation is the *protocol algorithm.* Cognitive scientists' *modus operandi is* to compare the *analytic algorithm* to the *protocol algorithm.* What should cognitive psychologists do with these two algorithms in the event that they do not match?

It is possible to change the *protocol algorithm* to fit the *analytic algorithm* because (a) the former is abstracted from a human cognizer's protocol, and (b) there are numerous ways to carry out the abstraction. However, underlying the decision to change the *protocol algorithm* to fit the *analytic algorithm* is the assumption that the *analytic protocol is* correct. The question becomes: why it is necessary to collect a cognizer's protocol if the *analytical protocol* is assumed true in the first place.

At the analytical level, more than one *analytic algorithm* may suffice to solve a cognitive problem. Hence, there is no *a priori* reason why the *analytic algorithm* cannot be changed. The ultimate objective of applying the research methodology of cognitive science, after all, is to explain human mental phenomena. However, as has been noted, the generality, objectivity, reliability or validity of the *protocol algorithm is* open to question. In short, the dilemma facing psychologists is not knowing what to do when the *analytic algorithm* and *protocol algorithm* do not agree because there is no *a priori* reason why one algorithm is more reliable or valid than the other.

RESEARCH INTEREST

The role played by *sufficiency* and *strong equivalence* in the *virtual machine model* is very informative as to the research interest of cognitive scientists. The *sufficiency* criterion shows that cognitive scientists are concerned with being able to describe how the mental apparatus is being utilized to perform specific tasks, not with the functional architecture itself. In other words, cognitive scientists take for granted the functional architecture when questions about *strong equivalence* arise. This may be seen from the fact that *strong equivalence* is to be found between a program and a mental activity, not between a virtual machine and a human mind.

What concerns cognitive psychologists, on the other hand, are the theoretical properties of the functional architecture of the mind. Some examples are (a) whether or not identity information is available at the level of the visual sensory store (Chow, 1986, 1991; Merikle, 1980; Mewhort, Butler, Feldman-Stewart & Trainer, 1988; Mewhort, Campbell, Marchetti & Campbell, 1981), (b) why it is justified to treat the short-term store as a working memory (Baddeley & Hitch, 1974), and (c) whether or not episodic memory and semantic memory are structurally distinct systems (McKoon & Ratcliff, 1979; Tulving, 1983).

Even when cognitive psychologists do study a control process of memory, they study it as a means to learn something about a theoretical property of the structure of memory. That is, they are concerned with the mind's functional architecture. For example, Sternberg's (1967) study of memory scanning is as much about abstract visual representation in the short-term store as about the manner of retrieval. Similarly, chronometric studies of classification conducted by Posner and Mitchell (1967) are also empirical investigations of the abstract visual representation in the shortterm store.

In short, cognitive scientists and psychologists seem to have different kinds of research questions in mind. They also have different objectives when they seek to understand mental phenomena. Cognitive scientists take for granted what the mind is, including its theoretical properties (e.g., the *primitives* of the *virtual machine model),* and seek to examine how the mental apparatus envisaged in a *taken-for-granted* theory may be utilized to carry out a task for which an algorithm is available on analytical grounds. Psychologists, on the other hand, are concerned with theories about the mental apparatus itself. Meta-theoretical and methodological assumptions important for the type of research questions raised by cognitive scientists need not be appropriate for the types of research questions of interest to psychologists.

THE CIRCULARITY AND AD HOC ISSUES

Pylyshyn (1984) suggested that the *strong equivalence* criterion be used together with the *sufficiency* criterion so as to prevent cognitive scientists from accepting *ad hoc* or circular *sufficient* programs as explanatory accounts. Can cognitive psychologists avoid committing themselves to circular theories if they adopt the *strong equivalence* criterion? To answer this question, it is first necessary to make explicit what, an *ad hoc* theory, as well as what circularity, is.

The term *snake phobia* is introduced to describe someone who is afraid of snakes in an excessive, irrational way. That the term has no additional meaning renders it an *ad hoc* description of the phenomenon. At the same time, if the individual's excessive, irrational fear of snakes is used to justify why the individual is said to suffer from snake phobia, the explanation is a circular one.

A protocol algorithm is extracted from a participant's protocol. It has no additional meaning apart from being an adequate description of the protocol. It is, hence, an *ad hoc* description of the protocol. By the same token, if the validity of the *protocol algorithm* is to be established by appealing to the protocol from which the *protocol algorithm* is abstracted in the first place, the argument is circular.

As a precursor to examining whether or not the *strong equivalence* criterion can prevent cognitive psychologists from engaging in circular argument or subscribing to *ad hoc* theories, first consider (a) the differential roles of research data, and (b) the different relationships between a to-be-validated theory and the criterion used in establishing validity in cognitive science and cognitive psychology.

Role of research data - foundation or evidential?

Recall that research data from a protocol analytic study are a participant's protocol generated in the course of solving a problem. The theory, in the form of a *protocol algorithm,* is abstracted from the cognizer's protocol. This chain of events may be characterized as a *data-then-theory* sequence. Research data in this sequence are being used to build the *protocol algorithm.* Hence, they may be characterized as the *foundation data* for the theory thus abstracted.

The *data-then-theory* sequence envisaged in cognitive science is at odds with the actual practice of experimental psychologists (e.g., Collins & Quillian, 1969; Craik & Tulving, 1975; Posner & Mitchell, 1967; Sternberg, 1967). Contrary to cognitive scientists' assertion, cognitive psychologists do not abstract an explanatory theory from their experimental data. Instead, theorization begins with an everyday mental phenomenon (e.g., our subjective experience of being able to perceive at a glance more than what we can recall; see Sperling, 1960). A cognitive psychologist proposes an explanatory theory to account for the said phenomenon (e.g., Sperling's, 1960, *very short-term visual memory).* The next step is to derive from the tentative theory an implication which is a prescription as to what the evidential data should be like. An experiment is designed and data are collected in the way prescribed by the experimental design.

The chain of events implicated in an experimental study in cognitive psychology is best characterized as a *phenomenon-theory-implication-* sequence (see Chow's, *1992, prior data versus evidential data* distinction). It is important to emphasize that experimental data are not used to build a theory in cognitive psychology. Instead, they are used to assess the tenability of a theory. For this reason. research data in cognitive psychology may be characterized as the *evidential data* for the theory in question.

Theory and its validity criterion

As may be recalled, a theory in cognitive science is to be assessed by comparing it to an *analytic algorithm.* Important to the present discussion is the fact that there is neither a logical nor a theoretical relationship between the *protocol algorithm* and *analytic algorithm. A* particular *analytic protocol* is chosen because its implementation brings about results which mimic the performance on a specific task of a human cognizer (i.e., the *sufficiency* criterion). However, another *analytic protocol* may be equally *sufficient* for the job.

The validity of a theory in cognitive psychology is assessed by comparing experimental data to a deduction from the theory (viz., an implication of the theory). *Implication* in the *phenomenon-theory-implication-data* sequence in cognitive psychology has a logical or theoretical relationship to *theory.* More specifically, the implication is a prescription of what has to be true in order for the putative theory to be correct (e.g., partial-report superiority has to be obtained in order for Sperling's, 1960, *very short-term visual memory* to be tenable). In other words, the evidential data are the necessary condition for the tenability of the putative theory. As has been shown, this is not the case if psychologists rely on *strong equivalence.*

It is now possible to discuss the issue of circularity with reference to (a) the distinction between using research data as *foundation data* versus as *evidential data,* and (b) whether the relationship between a to-be-validated theory and the validity criterion is arbitrary (in cognitive science) or implicative (in cognitive psychology).

Circularity and *strong equivalence*

The circularity issue arises in cognitive science because research data are used as foundation data of the to-be-validated theory. That is, the *protocol algorithm* is an *ad hoc* description of its foundation protocol. Nonetheless, the *protocol algorithm* is theoretically useful if it can account for other phenomena. Circularity is avoided if the protocol algorithm is justified with evidence independent of the foundation protocol. Hence, Pylyshyn (1984) suggested using the analytical algorithm.

For Pylyshyn's (1984) *strong equivalence* criterion to work, however, it is necessary to show that the *analytic protocol* (a) is independent of both the foundation data and the to-be-validated *protocol algorithm,* and (b) can account for phenomena other than that represented by the *foundation* data. It is also necessary to give a logical or theoretical justification as to why the *analytic algorithm is* the validity criterion for the *protocol algorithm.* However, the *virtual machine model* is mute on these points. At the same time, there are reasons to believe that the *strong equivalence* criterion does not satisfy these requirements.

First, the foundation data in cognitive science (i.e., the protocol) are concomitant with the to-be-explained phenomena. Whatever is revealed by the protocol may be specific only to the particular problem a human cognizer is solving. This raises the question of generality. It also makes it doubtful whether or not the *analytic algorithm* can account for phenomena other than the foundation data.

Second, underlying the *analytic algorithm is* a higher-order theoretical perspective (Pylyshyn, 1984). The collation of the protocol and the extraction of the *protocol algorithm* may also be determined by the same higher-order theoretical perspective, particularly when the protocol also includes the researcher's remarks (see Newell & Simon, 1972, p. 163). In other words, neither the foundation data *(viz.* the protocol) nor the validity criterion (i.e., *analytic algorithm)* is independent of the to-be-validated *protocol algorithm.* In view of these two difficulties, it is not clear how matching a *protocol algorithm* to an *analytic protocol* would prevent a researcher from accepting a circular or *ad hoc* theory.

How is circularity avoided in cognitive psychology?

Circularity is not an issue for cognitive psychologists by virtue of their *conjectures and refutations* approach to theory corroboration (Popper, 1968a, 1968b). For example, Sperling's (1960) *very short-term visual memory* is not *ad hoc* with reference to the original, to-be-explained phenomenon (viz., our subjective experience that we can perceive at a glance more than we can recall later) for the following reason.

To account for the original phenomenon, all that is required of the *very short-term visual memory* is that it has a capacity larger than that of the acoustic-verbal-linguistic short-term store. However, also attributed to the putative *very short-term visual memory* are the stipulations (a) that it retains only sensory information (e.g., size, shape, color, brightness and spatial arrangement of elements), and (b) information is lost from this store within half a second. These additional theoretical properties render the theory not *ad hoc vis-a-vis* the to-be-explained phenomenon. Furthermore, these additional properties make it possible to explain new phenomenon with the *very short-term visual memory (viz.,* partial-report superiority is found in some well-defined conditions, but not in other well-defined situations). How this is possible may be seen as follows.

A cognitive theory proposed to explain a mental phenomenon is a conjecture, however educated, about the mental apparatus. To be amenable to rigorous tests, this conjecture has to be explicit about the theoretical properties of the mental structure (e.g., the large capacity and sensory nature of Sperling's, *1960, verv short-terra visual memory).* If a particular theory is true, the theoretical properties it attributes to the mind must have consequences (or behavioral exemplifications) other than the to-be-explained phenomenon. Deriving an implication from a to-be-validated theory is to specify what specific consequence should occur if the mental apparatus is set to work in a particular situation (viz., to perform on the partial-report task when the selection cue is the size of the stimulus letters). To conduct an experiment is to collect data in the particular situation stipulated by an implication of the theory. The theory is tentatively accepted as tenable if the prescription of an implication is met by experimental data (Chow, 1987).

Note that the experimental data thus collected are not dependent on the phenomenon which suggests the theory in the first place. Moreover, the tenability of the theory is justified, not by the original phenomenon, but by the experimental data (which are independent of the original phenomenon) collected for the specific purpose of testing the theory. The justification of the theory is hence not circular. Furthermore, the theory is prior to the data used to justify it (i.e., its evidential data). That is to say, the theory is not ad *hoc vis-a-vis* its evidential data. Acceptance of the theory on the basis of new and independent data means that the theory can account for phenomena other than the original one.

SUMMARY AND CONCLUSIONS

Pylyshyn's *(1984) virtual machine model* is discussed. An examination of its *strong equivalence* criterion reveals some important differences between cognitive science and cognitive psychology. More specifically, while cognitive scientists are interested in how a *taken-for-granted* mental apparatus is being utilized to carry out a particular task, cognitive psychologists are concerned with the mental apparatus itself. A theory in cognitive science is in the form of an algorithm. However, a theory in cognitive psychology is a statement about the putative properties of the mind. An algorithm is proposed to explain research data by cognitive scientists. Cognitive psychologists use experimental data to justify a speculative theory. The *analytic algorithm* used by cognitive scientists to justify a theory (i.e., a protocol algorithm) is not independent of the to-be-validated *protocol algorithm.* This makes it difficult to see how cognitive scientists can answer the circularity issue.

This discussion is not meant to question the important contributions of cognitive science in artificial intelligence, robotics or the construction of intelligent machines. It is an examination of whether or not it is advisable for cognitive psychologists to accept uncritically the meta-theoretical assumptions and methodology of cognitive science. My conclusion is that the *conjectures and refutations* approach (which has served cognitive psychology well) is still the more satisfactory approach to the study of our mental apparatus.

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