'Semantic Procedure' is an Oxymoron *

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1 Introduction

Johnson-Laird and Byrne are to be congratulated on proposing a new mechanism for deductive inference and for presenting extensive evidence for the psychological validity of this mechanism. I will have no quarrel with this mechanism or with the psychological claims; both deserve attention and further investigation. My argument is against the implied epistemic nature of the new

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mechanism.

In [Johnson-Laird & Byrne 91] the mental models mechanism is described as a "semantic procedure" (p23) and is said to be "compatible with the way in which logicians formulate a semantics for a calculus" (p36). Mental models are contrasted strongly with rule-based mechanisms (*e.g.* p23, p195). The implication, whether intended or not, is that the mental models mechanism directly addresses the problem of intentionality. A mental models based computer program, it seems, would automatically give meaning to computational states.

I will argue that this implication is wrong; mental models have no more to say about intentionality than rule-based mechanisms. The attachment of the adjective 'semantic' to a deductive mechanism, or to any computer program, is misleading and confusing. The phrase 'semantic procedure' is an oxymoron. Mental model and rule-based mechanisms differ only in degree and not in kind.

2 The Meanings of 'Semantics'

Unfortunately, the issue is clouded because the word 'semantics' is used in different ways by different communities. For instance, logicians use it to describe a mapping from the expressions of a logical theory to the 'meaning' of these

expressions. To give a semantics to a logic is to provide this mapping. Tarski provided a semantics for predicate calculus by showing how logical sentences in a theory could be mapped to truth or falsity in a model.

There is an ambiguity about whether these models are aspects of the real world or mathematical theories in their own right. For a semantics to map formulae to their meaning, models should be part of the real world. However, there are several forces encouraging their formalisation as mathematical theories. Formulae in commonsense reasoning are relatively easy to map to the real world. For instance, in $loves(John, Mary)$ the constants $John$ and $Mary$ map to specific individuals John and Mary, $loves$ to the relationship of loving and $loves(john, mary)$ to the assertion that John loves Mary. Mathematical formulae, *e.g.* $2+2=4$, are harder to map to the real world because the coherence of the mapping presupposes a platonic commitment to the existence of 2, 4, *etc.* Couple this with the natural tendency of mathematicians to formalise, and it becomes easier for them to regard models as mathematical theories of sets of objects on which functions and relations are defined. The sense of 'semantics' in which it assigns 'meaning' is then lost.

Linguists generally use 'semantics' to describe, not the mapping to a meaning, but the meaning itself. A semantic representation of a natural language sentence is contrasted with the syntactic representation. The syntactic rep-

resentation is the original string of words or a parse tree with these words labelling the leaves. The semantic representation must capture not this grammatical structure but its content. Confusingly, this is usually done by a logical formula; so the linguist's semantics is the logician's syntax!

Computer scientists use the word 'semantics' to describe the mapping from a programming language to a mathematical theory. Ironically, this turns the logician's usage on its head. Logical semantics translates a mathematical formula into a program for calculating a truth value; computer science semantics translates a program into a mathematical formula.

Because of their remark on p36 of [Johnson-Laird & Byrne 91] (see §1 above), I will assume that Johnson-Laird and Byrne intend the word 'semantics' in the logician's sense. I assume that their mental models are based on Tarski's models of logical theories; that their deductive mechanism is an attempt to reason in the model theory in contrast to rule-based mechanisms that reason in the proof theory. I claim that it is not possible to do this.

3 Is Semantic Reasoning Possible?

If we regard Tarskian models as part of the real world then reasoning with them would entail physically manipulating the real world. This has limited

utility. It is not possible to conduct forward planning, hypothetical reasoning, counter-factual reasoning or abstract reasoning by manipulating the current world state. We must reason by manipulating an internal representation of the world.

At this point the problems of intentionality emerge, *i.e.* we need a semantics to map this internal representation onto its meaning. This remains true even if the internal representation is based on a Tarskian model. Calling the manipulation procedure 'semantic' does not affect the situation.

Basing a computational reasoning mechanism on Tarskian models presents problems for an finite computer. For instance, some models have an infinite domain of objects. Some reasoning involves proving that an infinite collection of objects has a property. Some reasoning involves the representation and use of incomplete or vague information. These problems are solved in rule-based mechanisms by the use of quantifiers, variables, disjunction, *etc.* Some equivalent device is needed in model-based reasoners if they are to have the same reasoning power. Johnson-Laird and Byrne employ such devices in their mental models mechanism. For instance, infinite numbers of objects are represented by a finite number of tokens; incomplete information is represented by having alternative models to cover the range of possibilities.

4 Are Rule and Model-Based Reasoners Different in Kind?

One paradigm example of a rule-based deductive system is a resolution-based theorem prover. The rules are formulae of predicate calculus in clausal form representing the axioms of the theory and the negation of the conjecture. The conjecture is proved by *reductio ad absurdum*; the clauses are 'resolved' together, usually exhaustively, until the empty clause is derived.

However, resolution can also be viewed as a systematic attempt to check that none of the models of the theory provide a counter-example to the conjecture. The fact that resolution can be viewed in this way goes back to a meta-logical theorem of Herbrand's. If the attempt to prove the conjecture fails after a finite search, then a counter-example to the conjecture can be read off automatically from the failed attempt. Thus resolution can be viewed both as a rule-based and as a model-based mechanism!

This potential duality was brought home to me forcibly as a result of my first foray into automatic theorem proving. I built a model-based theorem prover for arithmetic called SUMS, [Bundy 73]. Its model consisted of a representation of the 'real line' as used by mathematicians in informal blackboard arguments. The hypotheses of the theorem were represented by placing points in appropri-

ate positions on this 'real line' and the conclusion was then read off from the model.

As I tried to get SUMS to prove harder and harder theorems this simple idea became more and more elaborate. For instance, consequences of the original hypotheses had to be propagated around the model before the conclusion could be read off. The natural propagation mechanism was forward-chaining with rules. After a while I realised that I had just built yet another rule-based mechanism. SUMS was now similar to a standard semantic tableau prover with a bottom up search strategy. SUMS' progression from model-based to rule-based was incremental. There was no point at which the nature of its reasoning dramatically changed in kind.

5 Conclusion

I have argued that there is no difference in kind between the mental models deduction mechanism of Johnson-Laird and Byrne and rule-based mechanisms. Indeed, it is possible to view many deduction mechanisms as simultaneously of both types. The issue of intentionality arises with both types of mechanism, and is not finessed by the use of a model-based approach. To the best of my knowledge Johnson-Laird and Byrne make no claim to the contrary. However,

others may erroneously draw that conclusion from the free use of words like 'semantics', 'model', *etc.* For this reason I recommend that the word 'semantics' be used with extreme caution. It is a highly ambiguous term and has great potential to mislead.

None of this detracts from Johnson-Laird and Byrne's significant contribution in defining a new deduction mechanism and providing evidence for its psychological validity.

References

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[Johnson-Laird & Byrne 91] P. N. Johnson-Laird and R. M.J Byrne. *Deduction.* Lawrence Erlbaum Associates, Hove and London, 1991.