In other situations, such as a timetable problem, where there is some uncertainty, but it is not so serious, the better strategy is to retain our common sense inferences, and explicate them for use on a computer. This results in a non-classical logic. PROLOG played an important role in bringing to light the logical form of some every day inferences which had been largely neglected when the focus was on the logic of inferences in mathematics. These every day inferences are still non-monotonic even if PROLOG is no longer much used by practical computer programmers, and so the support for the empiricist view of logic remains even if PROLOG is superseded.

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DISCUSSION

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SUMMARY The paper draws a sharp distinction between the empiricist view of logic introduced by Gillies, with particular reference to A.I. logic, and the view defended by Quine and Putnam, with particular reference to Quantum mechanics. Some observations on the current status of Quantum mechanics suggest a criticism of the latter view, i.e. of any reform of logic inspired by scientific theories and involving statements about the structure of the world. Gillies' view, being independent from ontological claims, is not subject to this criticism.

KEYWORDS Logic, Artificial Intelligence, Quantum Mechanics, Ontology

The most striking feature of Professor Gillies' paper is the fact that it includes in a single framework so many different and commonly separated issues, such as the empiricity of logic, quantum logic and artificial intelligence. I will not advance technical comments on the different branches of the argument. My main comment is about the very idea of an "empiricist view of logic": I will propose a distinction between the view supported by Quine and Putnam and Gillies' view.

First of all, let us articulate Gillies' argument into four main points.

First, he is "sympathetic" to the empiricist view of logic introduced by Quine (1951) and Putnam (1968).

Second, he believes—contrary to both Quine and Putnam—that Quantum Logic (QL) failed to provide a "clinching argument" in support of the empiricist view of logic, that is, a "clear case in which an alternative non-classical logic had been preferred to classical logic on empirical grounds."

Third, he introduces two arguments about alternative logics in A.I., which I will take for granted. Some of these logics, such as PROLOG non-monotonic logic, are not reducible to classical logic; moreover, they proved to be more efficient than classical logic in "different contexts and problem-situations."

Fourth, Gillies presents some observations about why QL failed to fulfill the empiricist view of logic, whereas PROLOG and similar alternative logics present a solid support for this view. Gillies argues that QL was not well accepted by physicists as a matter of fact, possibly because Quantum Mechanics (QM) presupposes in its formalism classical mathematics and logic. On the other hand, PROLOG logic did succeed in many application areas, even though it was not originally intended to replace classical logic. Therefore**,** in order to support the empiricist view of logic, we should employ the examples of A.I.

Starting from the first point, I want to make some historical remarks about Quine's and Putnam's views on the laws of logic. First it should be remarked that their conceptions, introduced by the common example of QL, are not identical. Quine presents the role of QL in the context of his criticism of the analytic-synthetic dichotomy. Putnam sticks to the dichotomy, but presents the laws of logic as examples of a third class of statements, the "framework principles," which are neither analytic nor synthetic (Putnam 1962). Given these slight differences, which I cannot discuss at length, Quine and Putnam do share a holistic epistemology. Indeed both Reichenbach and Quine's teacher Carnap developed a holistic view of scientific principles in their works of the 20s and 30s. What is original to Quine and Putnam, in this regard, is the idea that logical laws not only play a crucial role in physical science, but can be considered on the same level as physical laws.

Indeed, in contrasting Bohr's standard interpretation of QM, they could even be drawing from the same source of inspiration. Quine's example of the revision of the law of the excluded middle may have been inspired, not by Von Neumann and Birkhoff, who simply introduce a new *calculus* of quantum mechanics, but by the three-valued logic proposed by Reichenbach in 1944 as a possible *interpretation* of quantum mechanics, alternative to Copenhagen's interpretation.[4]

Reichenbach, in turn, was certainly a major source of inspiration for Putnam's "framework principles," and Putnam himself endorsed three-valued logic in Putnam 1954. In the 1968 paper, drawing inspiration from the operational definition of logical connectives in Finkelstein 1969 (presented in 1966), Putnam changed his view, turning back to the Von Neumann-Birkhoff calculus with no distributivity law. This change may have been inspired by Feyerabend's severe and convincing criticism of QL in a review of Reichenbach's reprinted book, where three-valued logic was charged with "removing from sight" the problems of QM as an ad hoc hypothesis with no empirical advantage (Feyerabend 1966, p. 328). Still, Putnam introduces QL not simply as a calculus for quantum mechanical *formalism*, but as an alternative to *interpretations* of QM such as complementarity or hidden variables.

As the parallel between QL and geometry in general relativity makes clear, according to Quine and Putnam the laws of logic do not simply provide an inferential apparatus for empirical science, but they have an ontological value: they concern the truth about how "the world" is. This idea goes far beyond what

[4] See Reichenbach 1944, I, p. 8. As a matter of fact, Quine would later repeat that Von Neumann and Birkhoff's calculus "lacks classical negation and, therewith, the law of the excluded middle" (Quine 1970, pp. 85–86). There seems indeed to be a misunderstanding in his reading.

Von Neumann and Birkhoff could have originally had in mind by "reading off" the logic from the quantum mechanical formalism. In Putnam's words, there is such a thing as a "physical logic": logic determines objective properties, taking the place of "dynamical" explanations.

Now, compare these views with the main features of PROLOG in Gillies' case study:

a) PROLOG logic is of "practical use" for dealing with "some everyday problems," and more generally, alternative logics can be appropriate in "different contexts and problem situations."

b) Even though "the use of a particular logic [such as PROLOG] in a particular context is justified by the experience of its successful application in that context," this does not imply any correspondence between the laws of logic and the structure of the world. In PROLOG and other non-classical systems of logic in A.I. "conclusions may be false," but this does not depend on a missing correspondence between the theory and experience, as would happen if the new logic had to be regarded as part of the "framework principles" of knowledge. Simply, the basic information may be mistaken or altered, for many different reasons (meteorological conditions, human error, human choice), which transcend the domain of logic. We can see, then, that logic here is still a method of inference, whose ontological commitment is given by the empirical information introduced by the user, and has no relation with its logical laws.

c) PROLOG "is not, and was never intended to be, a general system of logic designed to replace classical logic." Indeed, it is not designed for "constructing proofs in formal arithmetic, or real number theory."

At this stage, I can spell out my first conclusion. We should draw a distinction between the "empiricist view of logic" supported by Quine and Putnam on the one hand (EVL^{QP}) and by Gillies on the other hand (EVL^{G}).

According to EVL^{QP}:

- Non-classical logic reflects objective properties;

- Logical laws describe the structure of the world;

- Non-classical logic cannot be empirically tested in itself, but only together with a whole scientific theory: logical rules are "framework principles" as well as geometrical and physical laws;

- It is a "general" deductive logic: therefore, it should be able to include formal arithmetic, etc.

According to EVL^{G}:

- Non-classical logic solves problems without involving a whole theory about the world (starting information may be mistaken, and examined in other theories, possibly by different logics);

- Logical laws (e.g. negation by failure) do not reflect the structure of the world;

- Its efficacy can be empirically tested;

- It has no universal validity, but turns out to be more useful than classical logic for inferring information in particular application areas.

Now, in light of these distinctions, I want to comment on Gillies' account on the failure of QL. I agree that QL does not provide a "clinching argument" for any empirical view of logic. First of all QL, intended as an interpretation of QM, actually meets the strong requirements of EVL^{QP} but does not fit the requirements of EVL^{G}. Gillies observes that "only a tiny minority of the physics community have ever adopted his [Putnam's] approach," as alternative to, for instance, the Copenhagen interpretation or hidden variables theories. Moreover, he suggests that this may depend on the fact that "Quantum mechanics does indeed have very severe conceptual problems, but these appear to arise outside of the theory's mathematical apparatus." I completely agree with the latter statement, and I believe that it suggests the major reason for the scarce success of QL among physicists. Consider the result of applying QL to the problem of measurement. By “reading off” logic from the formalism, and eliminating the distributive law, Putnam is able to eliminate the paradoxes of the theory, for instance in the two-slits experiment. This happens at the high cost of giving up standard logic, a move which had already been criticized by Bohr and Born, and later by the large majority of physicists (see the account in Jammer 1974, pp. 350–400). Moreover, if a physicist decides to deny the Copenhagen (extra-logical) solution, and look for an alternative theory, he will find no help in QL, be it three-valued logic or any other. Commenting negatively on Reichenbach's “ad hoc hypothesis,” Feyerabend (1966, p. 327) observed that anomalies such as “the sudden collapse of the wave […] show that for any theory which consists of the mathematical formalism of quantum mechanics together with some exhaustive interpretation there exist refuting instances.” Commenting negatively on Reichenbach’s “ad hoc hypothesis,” therefore, he had already suggested the alternative possibility of revising the quantum formalism itself.

Indeed, QL could be considered an elegant solution insofar as alternative theories to standard QM (such as Bohmian mechanics) did not receive wide recognition among physicists. In recent years, the possibility of different “dynamical” solutions of the problem of measurement is widely recognized in the physics community, and physical research is leading to possible experimental predictions which would call for a modification of the quantum mechanical formalism itself (see e.g.: Penrose 1996; Adler & Bassi 2009). The case study of QL suggests the following conclusion: since any scientific system as a frame of reference is open to revisions, we should avoid drawing ontological conclusions by transferring the problem of a particular formalism to logic itself. Indeed Putnam himself in 1975, giving his 1968 paper the new title *The Logic of Quantum Mechanics*, may have thought of making a slight restriction on his claims.

This reflection throws more light on the different approach advocated by EVL^{QP} and EVL^{G} regarding scientific discovery and justification. Here we see another point of distinction between two views of logic which agree on both holism and revisability of logic. A.I. logic, far from hindering scientific progress, aims at developing an inductive logic and leads to the discovery of new empirical laws. The goals of this logic, which is both deductive and inductive, and some examples of its empirical success are expounded in Gillies (1996). By contrast, in Friedman’s recent reassessment of the idea of “framework principles,” QL is again seen as a possible source of revolutionary advancement in science, as it interprets QM from the “philosophical or meta-scientific level” (Friedman 2001, p. 123).[5] The role of philosophy does not include any inductive logic for scientific discovery and is limited to the introduction of new conceptual “possibilities” (indeed, given the historical references to Kant’s “constitutive principles,” one may even wonder if this is an empiricist view of logic anymore). On the other hand, in Gillies’ view, deductive and inductive logic are included in a single holistic system of premises, though the philosophical or ontological interpretation of scientific theory is not involved in the process of empirical testing.

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[5] The parallel with Friedman is historically grounded in the latter’s joint work on QL with Putnam (Friedman and Putnam 1978).

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