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The Work of John Corcoran: An Appreciation

Stewart Shapiro & Michael Scanlan

Introduction

This festschrift number of *History and Philosophy of Logic* recognizes the significant contributions made by John Corcoran to both of the fields represented in the title of this journal. Some of these contributions have been made in his insightful and original published contributions. In this paper we do not attempt a comprehensive survey of the work of John Corcoran. The sections following this introduction attempt to provide a reader's guide to some important themes in this published *oeuvre*. Inevitably, this means that some choice nuggets have been left out. One locale for these nuggets is in the many reviews that he has produced continuously over the years for *Mathematical Reviews*. Our own experience has shown that he labors over these with the same dedication as with full blown articles. Many of them include original work of his own related to the material under review and all provide a good general insight into the subject discussed in the reviewed material.

But publication alone is not why it is appropriate for John Corcoran to receive the honor of a festschrift. The contributors and many others in these fields recognize that his personal interactions with others have facilitated immensely the development of these fields. To spend time with him is to be in the midst of a flurry of phone calls and faxes. Philosophy and writing is a dialogic experience for him. To think is to explain your ideas to another person. We, as his students, have benefited immensely from this close intellectual interaction with a master scholar and thinker. But many who are not his students, his colleagues in many diverse areas of history, logic, and philosophy have had similar experiences which have enriched their own work. It is with this in mind that this festschrift number is dedicated to John Corcoran.

Aristotle's Logic

Corcoran is perhaps most well-known for is his careful analysis of Aristotle's assertoric syllogistic logic and his reconstruction of it as a natural deduction system. In doing this he was in conflict with the pioneering work of Łukasiewicz. He had recognized that the "traditional" accounts of Aristotle's syllogistic logic represented not the account given in the *Prior Analytics*, but two thousand years of accretion of such nonaristotelian material as the "dictum de omni et nullo" and "rules of the syllogism". In his own attempt to recreate the logical framework described in the *Prior Analytics* using the resources of twentieth century logic, Łukasiewicz turned to the logistic systems he was most familiar with. In this context, Aristotle's descriptions of the formal syllogistic moods, using schematic letters in Greek conditional sentence constructions, led Łukasiewicz to posit that for Aristotle a syllogism was a true (implicitly universally quantified) conditional in which the traditional premise forms, such as "All A are B" and "All B are C" are conjoined in the antecedent and the traditional conclusion, such as "All A are C", is the consequent of the conditional. Using this approach and some other principles gleaned from Aristotle's text and the early Peripatetic tradition Łukasiewicz created an axiomatized logistic theory of Aristotle's syllogisms resting on four axioms and an underlying propositional logic. These axioms were two laws of 'identity' ('All A are A' and 'Some A are A') and conditional formulas corresponding to the syllogistic moods Barbara and Datisi. From this basis he was able to deduce versions, in his formulation, of such Aristotelian principles as rules of conversion and all of the syllogistic moods mentioned by Aristotle. As Łukasiewicz himself pointed out, this system is not complete in allowing the deduction of every truth that could be formulated in its version of the language of syllogistic. Łukasiewicz was also scrupulous in not claiming that his deductive theory of the syllogism corresponded to Aristotle's own procedures for justifying the validity of the various syllogistic moods, notably Aristotle's 'reduction' of them to the four 'perfect' syllogisms of the first figure.

Corcoran's reading of Aristotle found him to be presenting a theory of *deductions*. As a historical matter, this turned on Corcoran's insightful reading of *syllogismos* as a valid argument with two or more premises in the categorical language. In Corcoran's Aristotle, syllogisms are not the traditional three-term, two-premise arguments in the categorical language. What is more, there are no invalid syllogisms. In addition to the premises and conclusions, some syllogisms incorporate steps of deduction which make it evident that the argument is valid. These are "perfect" (complete) syllogisms to which nothing needs to be added to make their validity evident. The four "perfect" syllogisms of the first figure have the special feature that with just their two premises and conclusion, it is already evident that they are valid.

Using this interpretative base combined with a careful reading of passages where Aristotle, in the traditional terminology, "reduces" the validity of syllogisms in the second and third figure to the validity of those in the first, Corcoran developed two formal deductive systems for the deductive language. Each of these somewhat different systems could plausibly be said to be implicit in Aristotle's practice in the *Prior Analytics*. What is more, Corcoran was able to prove that each of these systems provides a complete deductive system for Aristotle's categorical language (Corcoran, 1972). This, interestingly enough, was a result hinted at by Aristotle himself, but not proved.[1]

The deduction systems that Corcoran found in the *Prior Analytics* are "natural" deduction systems. That is, they are sets of rules for construction of sentence sequences. These rules are intended to model certain steps of epistemic insight. The Aristotelian natural deduction systems do not contain logical axioms. This contrasts sharply with the Łukasiewicz deductive system for Aristotelian logic. This system is an axiomatic theory for propositions about relations between species. This is what leads Łukasiewicz to state, "The Aristotelian theory of the syllogism is a system of true propositions concerning the constants A, E, I, and O." (1957, 20). For Łukasiewicz, the theory of the syllogism was an axiomatized theory about certain sorts of relations in the same manner as a theory of linear order. One involves the axiom "If Axy and Ayz, then Axz", while the other includes the axiom "If x<y and y<z, then x<z". In the Łukasiewicz system, theorems are derived from the axioms using an underlying (and unformulated by Aristotle) propositional logic.

It is characteristic of Corcoran that he saw his discovery of a natural deduction system in Aristotle as having wider significance both in an historical and a philosophical context. He notes the significance for historical interpretation of the contrast between his interpretation and that of Łukasiewicz. His analysis of this contrast is so important for understanding Corcoran's thought that we feel free to quote at length.

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[1] Independently and about the same time, Timothy Smiley of Cambridge University presented a natural deduction system for Aristotle's logic., which he proves complete relative to a semantics similar to that of Corcoran. Cf. T.J. Smiley, "What is a syllogism", *Journal of Philosophical Logic* 2 (1973) 136-154.

> My opinion is this: *if* the Łukasiewicz view is correct *then* Aristotle cannot be regarded as the founder of logic. Aristotle would merit this title no more than Euclid, Peano, or Zermelo insofar as these men are regarded as founders, respectively, of axiomatic geometry, axiomatic arithmetic and axiomatic set theory. (Aristotle would be merely the founder of 'the axiomatic theory of universals'.) Each of the former three men put down an axiomatization of a body of information *without* explicitly developing the underlying logic. … Łukasiewicz is claiming that this is what Aristotle did. In my view, logic must begin with observations explicitly related to questions concerning the nature of an underlying logic. In short logic must be concerned with deductive reasoning. (1974, 98)

Corcoran enunciates the historical importance of his work in the opening of this passage where he raises the surprising issue of whether we should count Aristotle as the "founder of logic". Not to do this would overturn more than two thousand years of scholarly consensus. As Corcoran points out, we could not attribute to Aristotle a treatment of logic, in the sense of present day textbooks of mathematical logic, if we were to adopt the Łukasiewicz interpretation.

There is a more important philosophical issue that Corcoran sees underlying this historical debate. That is the issue of "What is logic?". Corcoran's answer, in brief, is given at the end of the above passage. To be logic a study "must be concerned with deductive reasoning." This centrality of deductive reasoning is in turn for Corcoran the source of the importance of logic. This is because he sees deductive reasoning as one of the glories of the human condition and an important avenue of knowledge. What is more, it is an avenue of knowledge which, on reflection, clearly involves the realist distinction between truth and knowledge. In working to construct a deduction, it is clear that we are seeking knowledge of an implication relation which already holds or fails to hold.

This treatment of logic as a deduction focused enterprise is contrasted by Corcoran with treatments of logic as codifying certain high-level ontic information. These are the logics, amenable to Łukasiewicz, which are systems of logical truths, such as those of Frege and of *Principia Mathematica*. In later work, Corcoran draws the contrast as one between logic as "formal epistemology" and logic as "formal ontology".[2] The former gives centrality to logical implication, the latter to logical truth. In a variety of ways, Corcoran has developed the view that it is logical implication (and deduction) which is the correct basis for understanding logic.

Implication/Consequence

An important theme in Corcoran's work has been the philosophical explication of the notion of implication (also known as logical consequence or logical entailment). A large part of this theme has involved working to clarify and disentangle the explications of implication offered by a variety of authors. The clearest example of this is in his article "Meanings of Implication" (1973a). This is ostensibly a study devoted to discriminating the various ways in which the English word "implies" is used in logical contexts. As with most of Corcoran's articles, it is a fascinating mixture of philosophic taste and sensitivity with historical awareness. For instance, Corcoran provides a careful articulation of the similarities and differences between

[2] Cf. Corcoran 1994. This is a masterful treatment of the wider issues connected with the interpretation of Aristotle's logic.

Russell's notion of formal implication, Bolzano's account of implication and Tarski's 1936 account of logical consequence. The latter is, of course, distinct from the post-1945 model theoretic notion of logical consequence, which allows for variations of universes of discourse. A reader of Corcoran's 1973 article would not have been surprised to discover that the Tarski of 1936 is not the Tarski of current textbooks[3].

One reason for Corcoran's deep intellectual respect towards Tarski and for his efforts to explicate Tarski's work[4] was in the philosophic importance he placed on Tarski's work to clarify fundamental logical notions. This is not only in the much heralded definition of truth (for formal languages) but also in defining such concepts as definability and logical consequence. Tarski is also important for Corcoran because he identifies Tarski with the treatment of logic he found in Aristotle. As noted above, this treatment takes argument validity or logical consequence, and the associated process of deduction to prove consequence, to be the central objects of logical investigation. This contrasts with a tradition represented by Leibniz and Frege, among others, for which logical truth (or analyticity) is the central logical notion. This is also why he never tires of recommending to students and colleagues two "popular" articles by Tarski in which this viewpoint towards logic is clearly expressed. These are Tarski's 1937 paper "Sur la méthode deductive" and his 1969 article "Truth and Proof" in *Scientific American*.

As noted earlier, Corcoran's articles are best read as situated in a rich and unified view of the nature of logic and its history. It is his vision of the relation of implication or consequence as the Ariadne's thread of logic which has made explication of its various treatments a central theme

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[3] This divergence was later noted by John Etchemendy, "Tarski on truth and logical consequence", *Journal of Symbolic Logic* 53 (1988) 51-79.

[4] This is most notable in his re-editing (with Tarski's cooperation) and introduction to the second edition of *Logic, Semantics and Metamathematics*.

for Corcoran. This is despite the fact that it is the official topic of only three of his papers, "Meanings of Implication", already mentioned, and two more recent papers on information-theoretic logic, to be discussed shortly. Nevertheless, the centrality of this notion forms the spine for the discussions in many of Corcoran's other writings. For instance, his discussion (with Susan Wood) of the inadequacies of Boole's criteria for validity and invalidity of arguments in his formalism, presupposes a clear understanding on the part of the reader of the centrality of implication/validity in logic and of deduction as a procedure for revealing implication relations.

It is also the centrality of this notion for Corcoran which leads him to search, in good scientific fashion, for the limiting factors in our understanding of implication. This is part of why he edited the publication of Tarski's lecture "What are Logical Notions?" (1986a). As he notes in the first sentence of the editorial introduction to the Tarski article, he sees it as a continuation of Tarski's efforts to define logical consequence. The logical consequence relation on a language, as defined by Tarski in 1936, is sensitive to which of the elements of the vocabulary are treated as "logical" and so not transformable. Tarski himself noted in 1936 that "no objective grounds are known to me which permit us to draw a sharp boundary between the two groups of terms." (1936, 418-419). Subsequently, some attempts have been made to define the notion of logical terms of a language[5]. It is characteristic of Corcoran's concern to advance our understanding of the notion of consequence that he made efforts to arrange the publication of Tarski's own later reflections on this topic.

In recent years we have had the benefit of Corcoran's own investigations of the notion of implication. This has come in the form of what he calls "information-theoretic logic". This is

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5 For instance, I. Hacking "What is Logic?", *The Journal of Philosophy* 76 (1979), reprinted in the Hughes 1993.

based on taking seriously what many have viewed simply as a colorful traditional metaphor. In this metaphor the content of the conclusion of a valid argument is said to be already "contained in" or "involved in" the content of the premises. One often finds oneself telling students that tedious deductions are necessary to "unfold" or "unpack" information hidden in a set of propositions.

In his information-theoretic logic, Corcoran has presented a view of logic inspired by these metaphors. Here the role of content is played by "information". In Corcoran's approach what are considered in logic are not sentences of a language, but instead propositions about a fixed universe of discourse such as the universe of Gödel Arithmetic. For these propositions, Corcoran characterizes the notion of information content, as it were postulationally. Distinct propositions are equivalent if and only if they have the same information content. A set of propositions implies another if the information content of the implied proposition is all contained in the propositions of the set. A proposition is logically independent of a set of propositions if it contains information not contained in the set of propositions. A tautology contains no information and a contradiction contains all information (of a domain). As one would expect, a proposition and its negation have no information content in common. Importantly, Corcoran also postulates that a disjunction of two propositions contains exactly the information common to the two propositions.[6]

With these postulates demarcating the relations between standard logical concepts and the notion of propositional information content, Corcoran is able to develop a host of intriguing logical observations. One striking example is that the conjunction of the three Gödel axioms for arithmetic (zero is not a successor, every number has a unique successor, and the second-order

[6] Corcoran 1998, p. 115. These are also implicit, as postulates, in Corcoran 1995.

induction axiom) is a proposition that is informationally "saturated." Such a "saturation" cannot have (domain) information added to it without becoming a contradiction. Since a saturation is a maximal consistent set of information about the domain, it implies every proposition which is not inconsistent with it. Since a saturation implies every proposition or its negation, this gives us a distinct way of viewing the completeness of (second-order) Gödel Arithmetic. This notion of saturatedness is an alternative to viewing the completeness of the axioms as a consequence of their categoricity.

Corcoran groups an approach to logic which would associate categoricity with completeness (that is, a sort of model-theoretic approach) among what he calls "transformation-theoretic logic". These are the various "standard" accounts of logic based on some notion of logical form of propositions or sentences, along with an analysis of the logical validity of arguments as the impossibility of transforming a valid argument in certain ways (e.g. by a transformation from a proposition with one group of concepts to another, or from one interpretation to another, or by substitution of vocabulary items) into an argument with all true premises and a false conclusion.

In his recent papers on the contrast between information-theoretic logic and classical logic (Corcoran 1998, 1998a) Corcoran does not attempt to choose which of these is the correct account of various phenomena that occur under the heading of logic. What he does point out is that each seems to relate better to some of these phenomena than to others. For instance transformation-theoretic logic provides a clear rationale for the well-established practice of using countertransformations to produce such results as the independence of the parallel postulate in geometry or of the Axiom of Choice in set theory. On the other hand, a transformation-theoretic approach seems to put an impossible epistemic burden on knowledge of logical validity. Such knowledge would seem to amount to, on a transformation-theoretic account, knowledge of the nonexistence of a countertransformation among the infinity of transformations for any given argument. Information-theoretic logic, in contrast, treats argument validity as an intrinsic property of an argument. Someone who knows an argument is valid, on the information-theoretic account, only needs to know that the informational content of the conclusion is contained in that of the premises. This seems a much more tractable epistemic task, at least in the case of simple arguments.

Philosophy of mathematics/second-order logic

Corcoran's contribution to the philosophy of mathematics is an outgrowth of his work in logic and philosophy of logic. He pointed out that with the possible exception of modal logic, the vast majority of logical systems were developed with mathematics, and in some cases, only mathematics, in mind. From Frege onward, logicians were primarily interested in the logic *of mathematics*. Some, such as Frege, Russell, Skolem, Hilbert, and Tarski, turned to logic as a way to illuminate the practice and goals of mathematics. Other logicians looked to mathematics as the best exemplar of their main interest, the general study of correct deductive reasoning. Mathematics provides a laboratory for extended deductive argumentation.

One question that is rarely asked concerns the relationship between a logical system and the body of reasoning it is aimed at. What are we out to capture with a logical system? What exactly is being claimed on behalf a proposed logical system *S* with respect to what it is supposed to be the logic of (e.g., mathematics or one of its branches)? A related sub-question concerns the relationship between the formal language of a logical system and the language in which ordinary reasoning, or mathematical reasoning, takes place.

Corcoran's answer is that a logic is a mathematical model of correct reasoning for a particular discourse, in much the same sense that a system of point masses is a model of interacting physical objects, a system of equations is a model of the bacteria in Lake Erie, or a topological space is a model of knots. Logic sheds light on correct reasoning in the same way that any mathematical model sheds light on what it is a model of. In each case, one can inquire into the features of a given model that correspond to features of the reality being modeled. That is, we ask about the *match* between model and modeled.

Typically, models are not perfect matches of the reality they model. Simplifying assumptions and idealizations are made, and so we can inquire into *mismatches* between model and modeled. A physical object is not a point mass, space is not frictionless, etc. A good model must capture essential features of what it is a model of, and yet it must be simple enough to work with. So it is with logic vis-à-vis deductive mathematical practice. Once we note the idealizations, we can seek "more realistic" models that are perhaps less simple but come closer to what is being modeled. This happens, for example, when we take volumes and friction into account when modeling interacting physical objects.

Corcoran's work in philosophy of mathematics addresses these issues concerning logic (the model) and mathematical practice (the modeled). He illustrates his orientation to logic (vis-à-vis mathematics) with a passage from Bourbaki's "Foundations of mathematics for the working mathematician"[7] :

> By proof, I understand a section of a mathematical text . . . Proofs, however, had to exist before the structure of a proof could be logically analyzed; and this analysis . . . must have rested . . . on a large body of mathematical writings. In other words, logic, so far as

[7] *Journal of Symbolic Logic 14* (1949) pp. 1-8.

> . . . mathematicians are concerned, is no more and no less than the grammar of the language which we use, a language which had to exist before the grammar could be constructed . . . The primary task of the logician is thus the analysis of the body of mathematics texts.

As indicated by the title of one of Corcoran's earliest papers, 'Three logical theories' (1969), different types of logical systems capture different aspects of correct (mathematical) practice. *Logistic systems* aim to codify logical truths, and succeed when weakly sound and weakly complete. *Consequence systems* aim to codify logical consequence (and so also logical truth), and succeed when strongly sound and strongly complete. Finally, *deductive systems* aim to capture, or model, the notion of a correct, rigorous deduction. So the rules of inference in a deductive system should correspond to natural, rigorous inferences in mathematics; inferences that are free of missing steps. A rule of inference should correspond to a (correct) move that a mathematician makes when asked to provide maximal logical detail, or what mathematicians call 'tight proofs'. This requirement on deductive systems is the analogue of soundness. Ideally, every *primitive* deductive move made by a mathematician should correspond to a rule of inference in a given deductive system. This corresponds to the criterion of completeness. Corcoran realized that there is nothing corresponding to soundness and completeness *theorems*, since, unlike the notions of logical truth and logical consequence, the notions of rigorous proof and primitive inference have not been characterized with sufficient precision. His paper calls for work on this.

The concern with rigorous deduction traces back (at least) to Frege's logicism. In order to determine if a theorem of mathematics is analytic, we have to break down its proof into minimal steps, to make sure that intuition or observation has not crept in at any stage. The notion of a rigorous proof that is free of missing steps is thus crucial to Frege's program, but Frege did not attempt to codify that notion, developing a logistic system instead.

The concern with the mismatches between logic and mathematics is explicitly pursued in Corcoran's "Gaps between logical theory and mathematical practice" (1973). He identifies several sources of inadequacies concerning standard logical systems vis-à-vis the literature of mathematics. One group of gaps consists of underlying logics of certain activities that have "never been modeled at all or else so inadequately that the existing models are almost useless". Another type of gap consists of underlying logics that have been modeled, but only inadequately. A third type of gap consists of "concepts and distinctions which arise in underlying logics, but for which no accounts have been given in mathematical logic". Some models have "defects" in that there are important aspects of the underlying logic (the item being modeled) that are not captured in the model. Models may also have "excesses", components that do not correspond to anything in the underlying logic being modeled.

The article provides an extensive list of gaps of the second and third type. Examples include different kinds of quantifiers, variable-binding operators, relations and connectives with an undetermined number of relata, derived rules, definitions, and non-denoting terms. To the contemporary reader, some of these gaps are straightforward to plug, while others remain elusive. This article anticipates much of the subsequent work in logic, concerning, for example, free logic and different types of quantifiers.

Corcoran's interest in second-order logic was pursued in the "Gaps" article, at a time when interest in second-order logic had waned, in part due to Quine's attack on it. The induction principle of arithmetic is that any property that holds of zero and is closed under the successor function holds of all natural numbers. Corcoran points out that this principle was historically presented as a second-order sentence. The induction principle cannot even be expressed in a first-order language that has no variables ranging over sets or properties. The usual move is to present the induction principle as an axiom *scheme*. If (*x*) is an formula of the first-order language of arithmetic, then

(0) & *x*((*x*) (*sx*))) *x* (*x*)

is an axiom of first-order arithmetic. So first-order arithmetic has infinitely many induction axioms, one for each formula of the language. Corcoran argues that this is a gap between logical theory and mathematical practice. The induction principle entails each instance of the scheme, but the instances, taken together, do not entail the induction principle. Moreover, there is something problematic in claiming that a mathematical theory with infinitely many axioms captures (or accurately models) the pre-formalized practice. This section of the paper anticipates much of the subsequent work on the revival of second-order logic.

The opening sections of "Categoricity" (1980) reiterate a distinction that figures prominently in several of Corcoran's earlier works (e.g., (1972a)). An argument is *semantically valid* if its conclusion is true on any interpretation (of the non-logical terminology) in which its premises are true, and an argument is *deductively valid* if it is possible to deduce its conclusion from its premises. The former notion focuses on the role of formal languages to describe various structures. A theory is *categorical* if all of its models are isomorphic to each other. A categorical theory is semantically complete in the sense that for any sentence in the language of the theory, either or its negation is a semantic consequence of the theory. However, a categorical theory may not be deductively complete. There may be sentences such that neither they nor their negations are deducible from the axioms of the theory.

The completeness and Löwenheim-Skolem theorems entail that no first-order theory with an infinite model is categorical. So there are non-standard, or unintended models of first-order arithmetic, real analysis, set theory, etc. Corcoran's extensive study delimits the resources a language must have in order to allow categorical characterizations of infinite structures. The compactness of first-order logic represents another gap between mathematical practice and first-order logical theory.

The results developed in the article strongly highlight the difference between the description of a structure and the codification of the reasoning in the corresponding theory. Corcoran provides a categorical description of the natural numbers such that hardly any interesting properties of the natural numbers can be deduced from it. He shows how higher-order logic has a crucial role in both the deductive and semantic pursuits.

The focus of "Second-order logic" (1987) is the role of higher-order languages in organizing the *theory* of deduction, and in illuminating logical forms. Corcoran shows how the introduction of *first-order* variables (and common nouns) organizes a logical theory, by collecting together a number of valid arguments under a single logical form. That is, first-order formal systems illustrate the logical form common to many arguments, themselves expressible without the resources of first-order logic. Similarly, Corcoran shows how second-order formal systems collect together a number of valid arguments under a single logical form. The arguments are themselves expressible in a first-order language, but we have to invoke a higher-order language in order to express the common form of the arguments.

Conclusion

We have attempted to show that the publications of John Corcoran are unified by a philosophic and historical sensibility which may not be apparent from a casual perusal of titles. This is not to say that that there are not one time treatments of a distinct topic that catches his attention. Some of his importance is his ability to bring fresh insight and rigor, based on well honed logical skills, to seemingly well-plowed areas. One favorite example is the abstract "Ockham's syllogistic semantics" (1981). Here he shows that even though Ockham in *Summa Logicae* advanced a peculiar semantics for categorical propositions which allowed for vacuous terms, nevertheless Aristotle's deductive system is both sound and complete relative to this semantics.

The fields of history and philosophy of logic have benefited both separately and jointly from the writings and interactions of John Corcoran. We look forward to many more writings and interactions.

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