axioms

Article

Term Logic

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Received: 19 December 2019; Accepted: 6 February 2020; Published: 10 February 2020

Abstract: The predominant form of logic before Frege, the logic of terms has been largely neglected since. Terms may be singular, empty or plural in their denotation. This article, presupposing propositional logic, provides an axiomatization based on an identity predicate, a predicate of non-existence, a constant empty term, and term conjunction and negation. The idea of basing term logic on existence or non-existence, outlined by Brentano, is here carried through in modern guise. It is shown how categorical syllogistic reduces to just two forms of inference. Tree and diagram methods of testing validity are described. An obvious translation into monadic predicate logic shows the system is decidable, and additional expressive power brought by adding quantifiers enables numerical predicates to be defined. The system's advantages for pedagogy are indicated.

Keywords: term logic; Franz Brentano; Lewis Carroll; logic trees; logic diagrams

1. Terminology

A *term logic* is one in which the only categorematic expressions are terms, that is to say, nominal expressions. Examples of terms from ordinary language are: singular terms, such as 'Socrates', 'the North Pole', 'Vulcan'; plural terms, such as 'the Beatles', 'the signatories to the Geneva Convention'; and general terms, such as 'planet', 'black dog', 'negatively charged particle'. From this, it will be seen that the presence or absence of a definite article makes no difference to whether an expression is a term or not. It will further be seen that terms may be simple or complex. In term logic itself, we will employ mainly term variables: there will be only two constant terms, given below. All other expressions in a term logic are formal, or what were once called syncategorematic. They are the logical constants needed to form sentences using terms, and such operators on terms as may form complex terms from simpler ones, and the logical connectives of propositional logic. Quantifiers will be added later.

The syllogistic of Aristotle and his successors was a term logic, as was that of such logical algebraists as Leibniz, Boole, Jevons, Venn and Neville Keynes. Term logic was augmented by relational expressions in De Morgan, Peirce and Schröder, but terms, except for singular terms, disappeared altogether from the predicate logic of Frege, Russell and their successors. An exception was the logical system of Leśniewski, who retained plural and general terms, though Leśniewski's system was also a predicate logic rather than a purely term logic. Term logic is a very natural medium for representing many inferences of ordinary discourse, more natural indeed than standard predicate logic. Though it has much less expressive power than predicate logic, being in its elementary form equivalent to monadic predicate calculus, it has much to recommend it from a pedagogical point of view, a fact recognised by Łukasiewicz, whose university textbook *Elements of Mathematical Logic* [1] augmented propositional calculus not with predicate calculus but with Aristotelian syllogistic.

The version of term logic we shall present owes much in inspiration to the logical reforms of Franz Brentano [2–4] with some influence from the logical writings of Lewis Carroll.

2. Language

2.1. Grammar

The grammar of our language will be categorial, with two basic categories: sentence (s) and term (n). (It is standard in categorial grammars to notate the nominal category by 'n' for 'name' rather than 't' for 'term'. We are following this tradition notationally, though we call the category by the older expression 'term'.) A functor category, the category of functor expressions taking arguments of categories $\beta_1, \ldots, \beta_n$ as arguments and forming an expression of category α, will be denoted as $\alpha\langle\beta_1 \ldots \beta_n\rangle$.

2.2. Basic Vocabulary

The Table 1 Basic Vocabulary below gives the basic expression used, together with their syntactic categories, categorial indices, and how we describe them.

Table 1. Basic Vocabulary.

Category	Index	Expressions	Description
Monadic Connective	s⟨s⟩	~	Sentential negation
Dyadic Connectives	s⟨ss⟩	$\wedge \vee \rightarrow \leftrightarrow$	[Standard]
Term Variables	n	$a, b, c, a_1, a_2, \ldots$	
Term Constant	n	Λ	Empty term
Monadic Term Functor	n⟨n⟩	′	Term negation
Dyadic Term Functor	n⟨nn⟩	[juxtaposition]	Term conjunction
Monadic Predicate	s⟨n⟩	N	Non-existence predicate
Dyadic Predicate	s⟨nn⟩	=	Identity predicate

The intended meanings of the term-logical constants are given in the Table 2 below:

Table 2. Meanings of Basic Term-Logical Constants.

Expression	Meaning	Example
Λ	Non-existing thing	
a'	non-*a*	non-animal
ab	*a* which is a *b*	doctor who is a musician
N*a*	there are no *a*	there are no unicorns
$a = b$	to be *a* is (the same thing as) to be *b*	to be a widow is to be a woman whose husband has died

2.3. Basic Syntax

In the interest of simplicity and brevity of expression, we delicately abuse the use/mention distinction and do not introduce special metavariables.

2.4. Terms

Any term variable or term constant is a term
If *a* is a term, so is $(a)'$
If *a* and *b* are terms, so is (ab)
Nothing else is a term except as allowed by definitions.

2.5. Sentences

If *a* and *b* are terms, $a = b$ is a sentence

If a is a term, Na is a sentence
If p is a sentence, so is ~(p)
If p and q are sentences, so are $(p \wedge q)$, $(p \vee q)$, $(p \rightarrow q)$ and $(p \leftrightarrow q)$
Nothing else is a sentence except as allowed by definitions.

We will omit parentheses where no ambiguity results. Propositional connectives are assumed to bind in the order negation, conjunction, disjunction, implication, equivalence.

3. Axioms

3.1. Propositional Logic Background

We presuppose without mention axioms sufficient for classical bivalent propositional logic, with substitution and modus ponens as inference rules.

3.2. Term-Logical Axioms

3.2.1. Intensional

for =

ID	$a = a$	(Identity)
LEIB	$a = b \rightarrow (p[a] \rightarrow p[b])$	(Leibniz)

where $p[x]$ is any sentential context containing the term x.

Justification

Self-identity and Leibniz's Law are standardly characteristic of identity.

for = and term conjunction

IDEM	$aa = a$	(Idempotence)
COMM	$ab = ba$	(Commutativity)
ASSOC	$a(bc) = (ab)c$	(Associativity)

Justification

For idempotence: to be an a which is an a is the same thing as to be an a
For commutativity: to be an a which is a b is the same thing as to be a b which is an a
For associativity: to be an a which is a (b which is a c) is the same thing as to be an (a which is a b) which is a c.

for = and ′

DN	$a'' = a$	(Term Double Negation)

Justification

To be a non-non-a is the same thing as to be an a.

for =, ′ and term conjunction

DIST	$a(bc)' = ((ab')'(ac')')'$	(Distribution)

Justification

This is the least self-evident of our axioms. It can be made more evident by considering an empty Venn or Carroll diagram for three terms and their negations: the three out of eight cells indicated by the left-hand side of the identity are the same as those picked out by the right-hand side, namely the cells for abc', $ab'c$ and $ab'c'$. Given the De Morgan definition of Term Addition ADD below, it permits the derivation of the desirable distribution laws DIST1 and DIST2 below.

3.2.2. Extensional

for N and Λ

HEID	NΛ	(Heidegger's Law)

Justification

There is no thing which does not exist.
for N and term conjunction
NWK $\mathrm{N}a \rightarrow \mathrm{N}ab$ (N-Weakening)

Justification

If there are no *a*s, there are no *a*s which are *b*s.
for N, term conjunction and ′
TNC $\mathrm{N}aa'$ (Term Non-Contradiction)

Justification

There are no *a*s which are non-*a*s. This is the term-logical version of the Principle of (Excluded) Contradiction, going back to Aristotle.
NEXH $\mathrm{N}ab \wedge \mathrm{N}ab' \rightarrow \mathrm{N}a$ (N-Exhaustion)

Justification

If there are no *a*s which are *b*s, and no *a*s which are non-*b*s, then there are no *a*s (at all).

3.3. Definitions

The Table 3. below gives definitions of the constant expressions we define using the basic ones. The form is either an identity for terms or a propositional equivalence for functors.

Table 3. Definitions.

Name	Definition	Description	Reading
UN	$\mathrm{V} = \Lambda'$	Universal Term	thing; object
ADD	$a + b = (a'b')'$	Term Addition	*a* or *b*
EX	$\mathrm{E}a \leftrightarrow \sim\mathrm{N}a$	Existence	There are *a*; *a* exist
NO	$a \mid b \leftrightarrow \mathrm{N}ab$	Universal Negative	No *a* are *b*
ALL	$a \subset b \leftrightarrow \mathrm{N}ab'$	Universal Positive	All *a* are *b*
SOM	$a \,\Delta\, b \leftrightarrow \mathrm{E}ab$	Particular Positive	Some *a* are *b*
AEQ	$a \equiv b \leftrightarrow \mathrm{N}ab' \wedge \mathrm{N}ba'$	Term Equivalence	The *a* are the *b*

These readings should be self-evident. The definitions NO, ALL and SOM are due to Brentano [2] (p.121) [4,5].

4. A Few Theorems

IDAEQ $a = b \rightarrow a \equiv b$ NC, LEIB, aeq AEQ
(Identity entails Equivalence)
EWK $\mathrm{E}ab \rightarrow \mathrm{E}a$ NWK, contrap., EX
(Existential Weakening)
EEXH $\mathrm{E}a \rightarrow \mathrm{E}ab \vee \mathrm{E}ab'$ NWK, contrap., EX
(Existential Exhaustion)
TDS $\mathrm{E}a \wedge \mathrm{N}ab \rightarrow \mathrm{E}ab'$ NEXH, contrap., EX
(Term Disjunctive Syllogism)
DIST1 $a(b + c) = ab + ac$
(Distribution, First Form)

Proof.

$a(b + c) = a(b'c')'$ ADD
$= ((ab'')'(ac'')')'$ DIST
$= ((ab)'(ac)')'$ DN
= ab + ac ADD
DIST2 $a + bc = (a + b)(a + c)$
(Distribution, Second Form) □

Proof.

$a + bc = (a'(bc)')$ ADD
$= (((a'b')'(a'c')')')'$ DIST
$= ((a'b')'(a'c')')''$ rewrite
$= (a'b')'(a'c')'$ DN
$= (a + b)(a + c)$ ADD
EXCL $N(ab)' \leftrightarrow Na' \wedge Nb'$
(Exclusion) □

Proof.

1.	$N(ab)'$	A for CP (assumption for conditional proof)
2.	$N(ab)' \rightarrow Na'(ab)'$	nwk
3.	Na′(ab)	nc, nwk, assoc, comm
4.	$Na'(ab)'$	1, 2, MP
5.	Na′	3, 4, NEXH
6.	Nb′	similiter
7.	Na′ ∧ Nb′	5, 6
8.	$N(ab)' \rightarrow Na' \wedge Nb'$	1–7 CP
9.	Na′ ∧ Nb′	A for CP
10.	$E(ab)'$	A for RAA (assumption for reductio ad absurdum)
11.	$Ea(ab)' \vee Ea'(ab)'$	10, EEXH
12.	$Ea(ab)'$	2nd disjunct incompatible with Na' from 9
13.	$Eab(ab)' \vee Eab'(ab)'$	12, EEXH, term shuffling
14.	Contradiction: first disjunct by TNC, second contradicts Nb' from 9	
15.	$N(ab)'$	10, 14, *reductio*
16.	$Na' \wedge Nb' \rightarrow N(ab)'$	9–15 CP
17.	$N(ab)' \leftrightarrow Na' \wedge Nb'$	8, 16 □

Corollary. $N(a + b) \leftrightarrow Na \wedge Nb$
Some Sample Syllogisms BARBARA b ⊂ c, a ⊂ b ⊢ a ⊂ c

Proof.

1.	b ⊂ c	A
2.	a ⊂ b	A
3.	Nbc'	1, ALL
4.	Nab'	2, ALL
5.	Nabc′	3, NWK
6.	$Nab'c'$	4, nwk
7.	Nac'	5, 6, NEXH
8.	a ⊂ c	7, all

DARII $b \subset c, a \Delta b \vdash a \Delta c$ □

Proof.

1.	$b \subset c$	A
2.	$a \Delta b$	A
3.	Nbc'	1, all
4.	Eab	2, SOM
5.	Nabc′	3, NWK
6.	Eabc	4, 5, TDS, DN
7.	Eac	6, EWK
8.	$a \Delta c$	7, som

DARAPTI $Eb, b \subset c, b \subset a \vdash a \Delta c$ □

Proof.

1.	Eb	A
2.	$b \subset c$	A
3.	$b \subset a$	A
4.	Nbc'	2, ALL
5.	Nba'	3, ALL
6.	Eab	1, 5, tds, dn, comm
7.	$Nabc'$	4, NWK
8.	Eabc	6, 7, TDS, DN
9.	Eac	8, EWK
10.	$a \Delta c$	9, SOM □

DARAPTI is one of those syllogisms whose validity is dependent on existential import of the subject term of the two premises: this is made explicit as the first premise.

In fact, every valid categorical syllogism has one of just three forms. We let * be a toggle operator taking positive terms to negative terms and vice versa, that is, if a is positive $a^* = a'$, while if a is negative, $a = b'$, $a^* = b$. Then every syllogism has as its core one of the three valid inference forms

POSITIVE $Eab, Nbc^* \vdash Eac$ (cf. DARII)
NEGATIVE $Nab^*, Nbc \vdash Nac$ (cf. CELARENT)
IMPORT $Ea, Nab^*, Nbc^* \vdash Eac$ (cf. BARBARI)

All can be derived from one of these by choosing b or c to be positive or negative, relabelling, swapping the order of premises, and applying commutativity ($ab = ba$) to obtain simple conversion. Furthermore, either POSITIVE or NEGATIVE is derivable from the other via partial contraposition and relabelling, so in the end Aristotelian categorical syllogistic owes its validity to just two forms of syllogistic inference, with a little propositional help.

Before concluding this section, a word about the ironic designation 'Heidegger's Law'. The basic non-existence predicate 'N' is best read as "Nothing is (a)", and the definitionally empty term 'Λ' can often be read as 'nothing'. The axiomatic formula '$N\Lambda$' can then be read as 'Nothing is (a) nothing', or, with a little linguistic chivvying, 'Nothing noths' or *Das Nichts nichtet*. Of course, Heidegger did not intend to say anything so straightforward or trivial, but it does refute Carnap's claim that the sentence has to be nonsense. *Au contraire*: suitably understood, it is a logical law.

It may seem a little perverse to have based this logic on the negative idea of non-existence rather than the positive one of existence. Of course, it is possible to do it the other way around, but in general the axioms for N are more satisfyingly elegant than those for E.

5. Intension and Extension

One of the standard principles of the Boolean algebra that emerged from Boole's and others' work on the algebra of terms in the nineteenth century is that all empty terms are identical: we have, e.g., that $aa' = bb'$, $Na \wedge Nb \to a = b$, $Na \to a = \Lambda$. These are *not* theorems of our system and it is important to see why. Their analogues with equivalence '≡' replacing identity '=' *are* theorems, and if we were to add an axiom of extensionality

EXT $a \equiv b \rightarrow a = b$

they would be theorems, and there would be no distinction between identity and equivalence. Most nineteenth century algebraic logicians understood their logic extensionally, so would be happy with this simplification. However, Brentano was not, and nor am I. The axioms involving identity = and those involving non-existence N are distinct in intent. Existence and non-existence have to do, for the most part, with contingent facts: there are narwals; there are no unicorns. There are some non-contingent principles involving N, obviously, our axioms such as term non-contradiction, but the premises in syllogisms and the antecedents in NWK and NEXH are typically contingent in application to actual propositions and actual inferences.

As will be seen more clearly when we consider diagrammatic representation, the axioms governing identity have to do not with contingent propositions but with the framework of discourse within which propositions and inference are employed. In any of the syllogisms considered, we are looking at three terms, their negations and conjunctions. For three terms, there are eight maximally specific combinations of conjunction and negation, for example $ab'c$, and the question may then arise whether N or E is true of this term. The axioms governing identity (and conjunction and negation) are formal synonymies, there to tell us, in advance of any statements about what does or does not exist, when term expressions relate to the same possibilities. Of these, the most obvious perhaps is $a = a''$, term double negation. No contingent facts have any bearing on these two expressions' relating to the same possibility of existence or non-existence. For this reason, I call the principles governing '=' *intensional* and those governing 'N' *extensional*. That does not mean I here endorse a modal logic or possible worlds, simply that the role played by framework description is different from and prior to that played by questions of existence and non-existence.

6. Consistency

The system is consistent. In the empty universe, every term is empty, and the extensional axioms are trivially true. Interpreting identity as equivalence, so are the intensional axioms. The empty universe is expressly not ruled out by the system: the dual to Heidegger's Law, namely.

EV There is something (rather than nothing) is not a theorem, because it is false for the empty universe.

7. Decidability

It is well known that first-order monadic predicate logic is decidable [6]. We may interpret the term logic in monadic predicate logic by associating each term a with a monadic predicate A

$$a \mapsto Ax$$

the term Λ with a necessarily empty predicate, for example

$$\Lambda \mapsto \sim(x = x)$$

with complex terms as follows

$$a' \mapsto \sim(Ax)$$

$$ab \mapsto Ax \wedge Bx$$

and the predicates as follows

$$a = b \mapsto \forall x(Ax \leftrightarrow Bx)$$

$$\mathrm{N}a \mapsto \sim\exists x(Ax).$$

In this way, each formula of the term logic is correlated with a formula of monadic predicate logic. The interpretation validates extensionality. It can be seen that all the axioms of the term logic system are valid formulas of monadic first-order predicate logic, and the validity of a formula or inference with finitely many premises containing n term variables may be decided on a domain of no more than 2^n individuals.

8. Tree Proof Techniques

Formulas and inferences with finitely many premises may be tested for validity or invalidity using tree techniques. The basic ideas were presented earlier for a slightly simpler system, so we can be brief [7]. We assume that all rules for trees for propositional logic are available, and we confine attention to term formulas using only the basic vocabulary of term variables, Λ, =, ′, conjunction, and N, as well as propositional connectives. Any defined constants are eliminated first as per their definitions. The counterexample set of an inference to be tested consists of the premises together with the negation of the conclusion, or the negation of a formula if that formula's validity is to be tested. A tree starts with the counterexample set. It may then be extended according to the following rules:

1. In a formula, terms may be replaced by terms identical to them according to the intensional axioms.
2. Any sentence N(*ab*)′ may be replaced by the two sentences N*a*′, N*b*′ by EXCL.
3. These and DN may be used to drive term negations inwards so they only occur singly and modify term letters only.
4. A branch containing ~N*ab* may be extended by ~N*a*, or ~N*b*, or both. (In the next two rules, *b* is a term occurring in the premises but not occurring in *a*.)
5. A branch containing N*a* may be extended by N*ab* and by N*ab*′
6. A branch containing ~N*a* splits and continues with ~N*ab* in one branch and ~N*ab*′ in the other.
7. Open branches are extended until all variables from the premises occur in any remaining branch, with term negations inmost, i.e., modifying a single term letter or constant term. Branches close under the following conditions:
8. The branch contains two contradictory formulas, for example E*ab*′*c* and N*ab*′*c*
9. The branch contains a formula ~NΛ
10. The branch contains a formula ~N*aa*′.

If all branches close, the formula or inference is valid; if any branch remains open, the formulas along it may all be true and constitute a counterexample.

9. Diagram Techniques

Diagrams for deciding the validity of logical inferences go back centuries, but the first effective ones are due to John Venn [8]. The idea, as applied to term logic, is to start with a diagram consisting of as many areas, or *cells*, as there are conjunctions of all simple terms and their negations contained in an inference. If there are n simple terms, that will be 2^n cells. Venn's own curvilinear diagrams are inferior to the rectilinear ones proposed by Lewis Carroll, who ingeniously constructed diagrams for up to eight different simple terms, and indicated how to extend these further [9] (p. 245 ff.: "My Method of Diagrams". Carroll was incidentally the first to use trees as an aid for solving logic problems: *ibid*., 279 ff. Since one of his problems ("Froggy's Problem", *ibid*., 338 ff.) is a sorites in 18 terms, which would require a diagram with 262,144 cells, taxing human capacity to solve, further aids were clearly needed.) The method for term logic as for syllogistic is to shade out those cells corresponding to N propositions, and indicate by crosses those cells corresponding to E propositions. The chief difficulty is that an E proposition whose term is not a maximal compound of simple terms and their negations must straddle several cells disjunctively, a problem compounded in any term-logical formula or inference employing disjunction or its equivalent. For this reason, diagrams are practicable only for relatively small and straightforward problems. Trees branch easily, but the only way to branch a diagram is to treat several diagrams disjunctively.

An unfilled diagram for n term variables, with its 2^n cells, represents the framework within which N and E propositions employing these variables are to be represented, and is neutral with respect to such propositions. The axioms for identity are then to be understood as indicating different but formally equivalent ways in which cells or groups of cells are indicated. This is why they play a different role in the logic from the N and E propositions.

10. Quantifiers

It is natural to extend the term logic employed to date with variable-binding quantifiers. One reason is simply to enhance the representative scope of the system. Quantifiers binding term variables do not affect the decidability of the resulting system, (Ackermann, *loc.cit.*) but they bring greater expressive power. We take the universal quantifier as primitive and add the following axiom schemes, where A and B are sentences:

$$\text{QDIST} \qquad \forall a(A \rightarrow B) \rightarrow (A \rightarrow \forall a(B))$$

where a is any term variable which is not free in A;

QINST #x2200;$a(A) \rightarrow A[t/a]$

where t is a term expression (variable, constant or compound), $A[t/a]$ is the result of substituting t for all free occurrences of a in A, and no free occurrence of a in A is in a well-formed part of A of the form $\forall t(B)$ [10] (p. 172).

The particular quantifier may then be introduced in the standard way as dual of the universal:

$$\text{FORSOME} \qquad \exists a(A) \leftrightarrow {\sim}\forall a({\sim}A)$$

It should be noted that the particular quantifier does not in this system carry existential import. Since it is a theorem that ~EΛ, it follows that $\exists a({\sim}\mathrm{E}a)$, so the quantifier cannot very well mean 'there exists', but must mean, neutrally, 'for some'. If we wish to talk about existing things, we have the predicate 'E' to hand.

One of the ways in which quantifiers introduce greater expressive power is that they facilitate expressions of number. Hitherto, expressions of the form Ea only said that there is some a. This is compatible with there being one, two, . . . any number of as, and this is why the cells of any diagram for finitely many propositions need only be finite in number. Indeed, the terms need not denote individuals or pluralities of individuals at all: they could denote numberless stuffs, as do mass terms in ordinary language. The syllogism in Darii

All morphine is highly addictive
Some pain medication is morphine:

therefore Some pain medication is highly addictive
is no less valid for being about stuffs ("substances") rather than individuals. If we wish to introduce numbers, to count individuals or also consignments of stuff, we need quantifiers. Here is how to define 'at least two':

$$\geq 2 \qquad \mathrm{E}_{\geq 2}a \leftrightarrow \exists x(\mathrm{E}ax \wedge \mathrm{E}ax')$$

So we can define 'exactly one' as

$$=1 \qquad \mathrm{E}_{=1}a \leftrightarrow \mathrm{E}a \wedge {\sim}\mathrm{E}_{\geq 2}a$$

11. Pegagogical Advantages of Term Logic

For students coming to logic with little or no background except in propositional calculus, term logic is quite natural and easy to understand. It is close to natural language (no bound variables, quantifiers as phrases not operators, logical and grammatical form closely similar); by comparison with predicate logic, there is minimal paraphrasing required; it has a straightforward and intuitive denotational semantics requiring no set theory, and is easy to do without special symbols. It can be treated by methods building easily on those of propositional logic: semantic diagrams, natural deduction proofs, axioms and trees. It has an accessible metalogic: it is sound, complete, and decidable, uses finitistic methods, affords a variety of approaches and good illustration of basic concepts. In difficulty, it is only slightly more complex than truth-tables and natural deduction for propositional logic, and is readily scriptable should one wish to write suitable computer programs. For an introduction to the history of logic, it allows much greater scope for comparison than post-Fregean predicate logic. It allows a variety of bases, apart from the one we have chosen. Alternative bases are equational (Leibniz, Boole, Jevons), subsumptional (Leibniz, Peirce, Schröder), existential (Leibniz, Brentano, Carroll), traditional (Aristotle, Łukasiewicz), or based on the singular copula (Leśniewski, Słupecki). It admits of various extensions, most obviously by introducing predicates, especially relational predicates, but also modal [11], towards Leśniewskian logic [3,12], and introducing higher types, up to and including full simple type theory.

On the negative side, it delays students' encounter with ∀ and ∃, with relations and multiple generality, has rather few links to modern mathematics, and being now unorthodox, suffers from a modern textbook gap. Most textbooks highlighting term logic (Łukasiewicz excepted) are antiquated attempts to keep pre-Fregean logic alive, often for non-logical reasons.

Nevertheless, I hope enough has been shown in this paper to suggest that term logic, whether done this way or in some other way, remains worthy of the attention of logicians and teachers of logic.

Funding: This research received no external funding.

Conflicts of Interest: No conflict of interest.

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