What Problem Did Ladd-Franklin (Think She) Solve(d)?

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27 March 2023

Outline

- Who is Ladd-Franklin?
- What is the problem?
- What is her solution?
- What is her problem?

Christine Ladd-Franklin

- Born 1847, died 1930.
- Admitted to Johns Hopkins University in 1878, under the name "C. Ladd".
- Wrote a dissertation, "On the Algebra of Logic", under supervision of C.S. Peirce.
- Dissertation printed in 1883.
- Post-PhD work in psychology, esp. vision.
- Officially granted PhD in 1927, age 78.

Where the present talk started from

April 2018, workshop on Feminist Logic & Formal Logic. Frederique Janssen-Lauret mentioned CLF and how she had solved a problem that had concerned logicians since Aristotle. As a historian of logic, with special interest in women in logic, this caught my attention because:

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- Not only did I have no idea what this solution was,
- I also had no idea what problem it solved.

What's the problem? (1)

Susan Russinoff (1999):

> *In 1883, while a student of C.S. Peirce at Johns Hopkins University, Christine Ladd-Franklin published a paper titled On the Algebra of Logic, in which she develops an elegant and powerful test for the validity of syllogisms that constitutes the most significant advance in syllogistic logic in two thousand years. . . In this paper, I bring to light the important work of Ladd-Franklin so that she is justly credited with having solved a problem over two millennia old [Russinoff, 1999, p. 451, emphasis added].*

What's the problem? (2)

The problem that Aristotle posed and attempted to solve is to give a general characterization of the valid syllogisms [Russinoff, 1999, p. 452].

. . . though he did not succeed in providing a unified and complete treatment of the syllogistic argument. . . [Russinoff, 1999, pp. 453–454]

What's the solution?

Theorem

The argument of inconsistency,

$$(a \,\overline{\vee}\, b)(\bar{b} \,\overline{\vee}\, c)(c \vee a)\overline{\vee} \qquad \text{(II)}$$

is the single form to which all the ninety-six valid syllogisms (both universal and particular) may be reduced [Ladd, 1883, p. 40].

Proof.

Any given syllogism is immediately reduced to this form by taking the contradictory of the conclusion, and by seeing that the universal propositions are expressed with a negative copula and particular propositions with an affirmative copula [Ladd, 1883, p. 40]. □

Wait, the problem is *what?*

What is the “form” of a syllogism?

- Is it “figure”?
- Is it “mood”?

Syllogisms: A primer (1)

Definition

A *categorical proposition* is a subject-predicate proposition consisting of a subject term, a predicate term, a quality, and a quantity.

There are four types of categorical proposition recognised by Aristotle:

- a "All S are P" (universal affirmative)
- e "No S is P" (universal negative)
- i "Some S is P" (particular/partial affirmative)
- o "Some S is not P" (particular/partial negative)

Syllogisms: A primer (2)

Definition

A *syllogism* is a set of three categorical propositions which share amongst them three terms that each occur exactly twice. Two of the propositions are designated the premises, and the other is the conclusion.

The predicate term of the conclusion is the 'major' term; the subject term of the conclusion is the 'minor' term; the term that occurs only in the premises is the "middle term". It is a convention that the premise with the major term in it, the major premise, is written first.

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Note: This is *Aristotelian* rather than *Aristotle*.

Syllogisms: A primer (3)

	Ist Figure	IInd Figure
Major premise:	$P — M$	$M — P$
Minor premise:	$M — S$:	$M — S$:
Conclusion:	$P — S$	$P — S$

	IIIrd Figure	IVth Figure
Major premise:	$P — M$	$M — P$
Minor premise:	$S — M$:	$S — M$:
Conclusion:	$P — S$	$P — S$

Figure: The Four Figures

Syllogisms: A primer (4)

Ist figure	*P a M*	,	*M a S*	:	*P a S*	**Barbara**
	P e M	,	*M a S*	:	*P e S*	**Celarent**
	P a M	,	*M i S*	:	*P i S*	**Darii**
	P e M	,	*M i S*	:	*P o S*	**Ferio**
	P a M	,	*M a S*	:	*P i S*	**Barbari**
	P e M	,	*M a S*	:	*P o S*	**Celaront**
IInd figure	*M e P*	,	*M a S*	:	*P e S*	**Cesare**
	M a P	,	*M e S*	:	*P e S*	**Camestres**
	M e P	,	*M i S*	:	*P o S*	**Festino**
	M a P	,	*M o S*	:	*P o S*	**Baroco**
	M e P	,	*M a S*	:	*P o S*	**Cesaro**
	M a P	,	*M e S*	:	*P o S*	**Camestrop**
IIIrd figure	*P a M*	,	*S a M*	:	*P i S*	**Darapti**
	P i M	,	*S a M*	:	*P i S*	**Disamis**
	P a M	,	*S i M*	:	*P i S*	**Datisi**
	P e M	,	*S a M*	:	*P o S*	**Felapton**
	P o M	,	*S a M*	:	*P o S*	**Bocardo**
	P e M	,	*S i M*	:	*P o S*	**Ferison**
IVth figure	*M a P*	,	*S a M*	:	*P i S*	**Bramantip**
	M a P	,	*S e M*	:	*P e S*	**Camenes**
	M i P	,	*S a M*	:	*P i S*	**Dimaris**
	M e P	,	*S a M*	:	*P o S*	**Fesapo**
	M e P	,	*S i M*	:	*P o S*	**Fresison**
	M a P	,	*S e M*	:	*PoS*	**Camenop**

Reprise: What is the “form” of a syllogism?

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Another digression: Logical Hylomorphism

Hylomorphism in Aristotle: non-mereological, metaphysical hylomorphism, a combination of form and matter.

Alexander of Aphrodisias: mereological logical hylomorphism, applied to syllogisms.

Could *this* be the form we're looking for?

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No: For Alexander, form = figure. By the 14th C: form = mood.

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  Hardly likely.

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So what was she doing??

The Five Algebras of Logic

Ladd identifies five algebras of logic, due to:

- Boole (in *Laws of Thought*)
- Jevons [Jevons, 1864]
- Schröder [Schröder, 1877]
- McColl [McColl, 1877]
- Peirce [Peirce, 1867]

Her aim was to introduce a sixth that addresses what she sees as are the drawbacks of the previous attempts.

Terms

The basic component of Ladd's algebras is subject and predicate terms. Atomic subject and predicate terms (hereafter simply called 'terms') are indicated by, e.g., a, b, c. Ladd follows Wundt and Peirce in using ∞ as a term to represent the domain of discourse [Ladd, 1883, p. 19].

Complex terms can be formed from atomic terms as follows:

- $\bar{a} =$ "what is not a".
- $a \times b =$ "what is both a and b".
- $a + b =$ "What is either a or b".

At times, $a \times b$ will be represented as ab. Infinite series of $\times$ or $+$, or combinations of the two, are allowed. $\overline{\infty}$ is given its own symbol: 0 [Ladd, 1883, p. 19].

What can be done with terms

- The identity of the subject and predicate terms can be affirmed.
- The identity of the subject and predicate terms can be denied.
- Complex terms can be negated (Ladd identifies three ways: Boole/Jevons; DeMorgan; Schröder).

Identity propositions

There are two types of propositions in Ladd's algebra: "those which affirm the identity of the subject and predicate, and those which do not" [Ladd, 1883, p. 17].

In all six of the algebras under consideration (the original five plus Ladd's), identity propositions are expressed the same way, via equality:

$$a = b \tag{1}$$

Note that while Ladd uses a and b here, these identity propositions are not restricted to atomic terms; complex terms may also be used in place of a and b.

Some true identity propositions involving only positive terms

$$\begin{array}{l|l} aaa = a & a + a + a = a \\ abc = bca = cba & a + b + c = b + c + a = c + b + a \\ a(b + c) = (ab + ac) & a + bc = (a + b)(a + c) \end{array}$$

That is, $\times$ and $+$ are both idempotent, associative, and commutative, and $\times$ and $+$ both distribute over each other.

How identity should be understood

- NOT as the identification of two objects, picked out via constants in the logical language.
- BUT as indicating the intersubstitutability of the two logical expressions a and b, *salve veritate*.

$a = b$ is equivalent to the following two propositions [Ladd, 1883, p. 18]:

$$\text{There is no } a \text{ which is not } b. \tag{2}$$

and

$$\text{There is no } b \text{ which is not } a. \tag{3}$$

Categorical propositions in algebra (1)

We can either

> *assign the expression of the 'quantity' of propositions to the copula or to the subject [Ladd, 1883, p. 23].*

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- If it is assigned to the subject term, the only copula that is needed is identity. Boole, Schröder, Jevons

Categorical propositions in algebra (2)

	Traditional	Boole / Schröder	Jevons	McColl	Peirce
Uni-	All a is b	$a = vb$	$a = ab$	$a : b$	$a \prec b$
versal	No a is b	$a = v\bar{b}$	$a = a\bar{b}$	$a : \bar{b}$	$a \prec \bar{b}$
Part-	Some a is b	$va = vb$	$ca = cab$	$a \div \bar{b}$	$a \overline{\prec} \bar{b}$
ial	Some a is not b	$va = v\bar{b}$	$ca = ca\bar{b}$	$a \div b$	$a \overline{\prec} b$

In the Boole/Schröder approach, v is not a categorical term like a or b, but a special term that picks out an arbitrary indefinite class. Jevons's c works similarly, but he does not distinguish it in the way that v is distinguished; it can be any other class term [Ladd, 1883, p. 24].

Which way is preferable?

Advantages of Boole/Schröder/Jevons:

- Only one copula is necessary.

Advantages of McColl/Peirce:

- Copulas that include their quantity can be used to link either terms *or* propositions, so that, e.g., $a \overline{\prec} b$ can be read either "*a* is not wholly contained under *b*" or "*a* does not imply *b*" [Ladd, 1883, p. 24].
- There is a correspondence between the quantity of the copula and its quality. The universal copulas are positive (affirmative), and the partial copulas are negative [Ladd, 1883, p. 25].

Ladd's way

Instead of taking as basic:

(a)	$a \prec b$	"a is wholly b"
(o)	$a \overline{\prec} b$	"a is not wholly b

take:

(e)	$a \overline{\vee} b$	"a is-wholly-not b"
(i)	$a \vee b$	"a is-partly b"

Symmetry

Both $\vee$ and $\overline{\vee}$ are symmetric combinators: "the propositions $a \mathbin{\overline{\vee}} b$,$a \vee b$, may be read either forward or backward" [Ladd, 1883, p. 26]; inclusion statements using $\prec$ are asymmetric.

Inclusions can be converted into exclusions by changing the copula and the sign of the predicate [Ladd, 1883, p. 27]:

$$a \prec b = a \mathbin{\overline{\vee}} \bar{b}$$

Every exclusion is equivalent to a pair of inclusions, differing on which of the two terms you take as the predicate:

$$\begin{array}{ccccc} a \mathbin{\overline{\vee}} b & = & a \prec \bar{b} & = & b \prec \bar{a} \\ a \vee b & = & a \mathbin{\overline{\prec}} \bar{b} & = & b \mathbin{\overline{\prec}} \bar{a} \end{array}$$

Advantages of this approach

- Categoricals and hypotheticals are treated identically in the formal system [Ladd, 1883, p. 23].
- If we let p denote a premise and c a conclusion following from p, then we can express this consequent fact as either:

$$p \overline{\vee} \bar{c}$$

or

$$\bar{c} \overline{\vee} p$$

Existence and nonexistence claims

We can express existence and nonexistence claims via ∞:

$$x \mathbin{\overline{\vee}} \infty \tag{4}$$

means "x does not, under any circumstances, exist", and

$$x \vee \infty \tag{5}$$

means that "x is at least sometimes existent" [Ladd, 1883, p. 29].

Translating between propositions and terms

Unlike in the (pure) algebra of terms, the algebra of propositions does not have 0 [Ladd, 1883, p. 29]. As a result, we can drop reference to ∞ in contexts where it can be restored without ambiguity. Therefore, we can write (4) and (5) as:

$$x\overline{\vee} \tag{4'}$$

and

$$x\vee \tag{5'}$$

This notation allows us to translate from categorical propositions (e.g., $a \overline{\vee} b$ "No a is b") into statements about terms (e.g., $ab\overline{\vee}$ "The combination ab does not exist") [Ladd, 1883, p. 30].

The three subjects of symbolic logic

Ladd identifies three subjects of interest for any symbolic logic [Ladd, 1883, p. 30]:

- the uniting and separating of propositions.
- the insertion or omission of terms, or immediate inference.
- elimination with the least possible loss of content, or syllogism.

On the elimination of terms

> *The most common object in reasoning is to eliminate a single term at a time—namely, one which occurs in both premises [Ladd, 1883, p. 37].*

This goal of logic can be accomplished via the inference form "if a is b and c is d, then ac is bd [Ladd, 1883, p. 34]:

$$(a \,\overline{\vee}\, b)(c \,\overline{\vee}\, d) \,\overline{\vee}\, (ac \vee b + d) \tag{I}$$

By setting d equal to $\bar{b}$, so that $b + d = \infty$, we can rewrite (I) as:

$$(a \,\overline{\vee}\, b)(\bar{b} \,\overline{\vee}\, c)(c \vee a)\overline{\vee} \tag{II}$$

(going via the intermediate equation $(a \,\overline{\vee}\, b)(c \,\overline{\vee}\, \bar{b})(ac \vee \infty)\overline{\vee}$).

The main result (again)

Theorem

The argument of inconsistency,

$$(a \,\overline{\vee}\, b)(\bar{b} \,\overline{\vee}\, c)(c \vee a)\overline{\vee} \tag{II}$$

is the single form to which all the ninety-six valid syllogisms (both universal and particular) may be reduced [Ladd, 1883, p. 40].

Proof.

Any given syllogism is immediately reduced to this form by taking the contradictory of the conclusion, and by seeing that the universal propositions are expressed with a negative copula and particular propositions with an affirmative copula [Ladd, 1883, p. 40]. □

Rules for the validity of a syllogism

From this theorem a corollary follows, in the form of an easy to apply rule, stated in ordinary English, for identifying whether any syllogism is valid:

Rule

Take the contradictory of the conclusion, and see that the universal propositions are expressed with a negative copula and particular propositions with an affirmative copula. If two of the propositions are universal and the other particular, and if that term only which is common to the two universal propositions has unlike signs, then, and only then, the syllogism is valid [Ladd, 1883, p. 41].

This is Ladd-Franklin's famous "Antilogism".

An example

Example

The syllogism Baroco:

$$\begin{gathered}\text{All } P \text{ is } M\\ \text{Some } S \text{ is not } M\\ \therefore \text{Some } S \text{ is not } P\end{gathered}$$

is equivalent to the inconsistency

$$(P \mathbin{\overline{\vee}} \bar{M})(S \vee \bar{M})(S \mathbin{\overline{\vee}} P)\overline{\vee}$$

Aristotle already knew how to do this (1)

Aristotle reduced both

Baroco	**Bocardo**
All P are M	Some M is not P
Some S is not M	All M are S
$\therefore$ Some S is not P	$\therefore$ Some S is not P

to

Barbara
All M are P
All S are M
$\therefore$ All S are P

via *reductio ad absurdem*—that is, taking the contradictory of the conclusion and replacing one of the premises with it, and then making the contradictory of the replaced premise the conclusion.

Aristotle already knew how to do this (2)

That the rudiments of the antilogism are already incorporated in the Aristotelian reductions was noticed by Kattsoff:

> *This method is actually the method of indirect reduction which is denoted by the letter 'k' in the mnemonic names Baroko and Bokardo [sic]. The name antilogism was given to this by Mrs. Ladd-Franklin [Kattsoff, 1936, p. 385].*

How what Ladd does differs

However, instead of taking Barbara as basic and Baroco and Bocardo as derived, Ladd showed that one can take as "basic" the inconsistency of the following three claims:

All M are P
All S are M
Not all S are P

Any two of these propositions entails the denial of the third; which is to say that the contradictory of any of the propositions follows from the other two, which gives us all three syllogisms.

This is the sense in which the three syllogisms are reduced to one "form".

What's the benefit of doing this? (1)

First, Ladd says:

> *If for the usual three statements consisting of two premises and a conclusion one substitutes the equivalent three statements that are together incompatible. . . one has a formula which has this great advantage: the order of the statements is immaterial—the relation is a perfectly symmetrical one [Ladd-Franklin, 1928, p. 532].*

In addition to the symmetry of the relation, the result is

> *a source of great simplicity—there is only one valid form of the antilogism instead of the fifteen valid forms of the syllogism which common logic requires us to bear in mind [Ladd, 1883, p. 532].*

What's the benefit of doing this? (2)

Thirdly, both the simplicity and the symmetry can be improved upon if all of the three claims can be written as either (e) "No S are P" or (i) "Some S is P" claims, which can be simply converted.

If we admit 'infinite' terms, then this rewriting into symmetric propositions is always possible, as "All S are non-P" is equivalent to "No S is P", and "Some S is not P" is equivalent to "Some S is non-P" (cf. [Reichenbach, 1952, p. 1]).

What did Ladd think she was doing?

Ladd herself hardly refers to Aristotle in her writings: She was developing Boole's algebra, not Aristotle's syllogism, and did not see herself as solving a problem that had plagued the syllogism for two millennia.

According to Ladd, her algebra, including the antilogism, "contains a solution of what Mr. Jevons calls the 'inverse logical problem'" [Ladd, 1883, p. 50]. The *Inverse Problem* is:

> *given certain combinations inconsistent with conditions to determine those conditions [Jevons, 1880, p. 252].*

The Inverse Logical Problem

A more precise characterisation of the *Inverse Logical Problem Involving Three Terms* is given in [Jevons, 1874, p. 157]:

> *Three terms and their negatives may be combined... in eight different combinations, and the effect of laws or logical conditions is to destroy any one or more of these combinations. Now we may make selections from eight things in* 2^8 *or 256 ways; so that we have no less than 256 different cases to treat, and the complete solution is at least fifty times as troublesome as with two terms... The test of inconsistency is that each of the letters* A, B, C, a, b, c *shall appear somewhere in the series of combinations; but I have not been able to discover any mode of calculating the number of cases in which inconsistency would happen... an exhaustive examination of the combinations in detail is the only method applicable [Jevons, 1874, pp. 157–158].*

Solving the Inverse Logical Problem (1)

The solution that Jevons provides "consists in inventing laws and trying whether their results agree with those before us" [Jevons, 1880, p. 252].

Both Schröder and Boole also tried to solve the problem:

> *The task which Boole accomplished was the complete solution of the problem:—given any number of statements, involving any number of terms mixed up indiscriminately in the subjects and the predicates, to eliminate certain of those terms, that is, to see exactly what the statements amount to irrespective of them, and then to manipulate the remaining statements so that they shall read as a description of a certain other chosen term (or terms) standing by itself in a subject or predicate [Ladd Franklin, 1889, p. 543].*

Solving the Inverse Logical Problem (2)

Though Boole's rule gets the conclusion right, Ladd is nevertheless critical of it. She quotes Venn, who said that Boole's method was "a terribly long process" [Ladd, 1883, p. 50], more theoretical than practical. Further than that, Boole's form of the conclusion would have to be altered to fit the notation of her algebra, and is also "not that which is most natural or most frequently useful" [Ladd, 1883, p. 50]. This is because it is "suited only to a logic of extension" and does not work well under an intensive interpretation [Ladd, 1883, p. 50].

Solving the Inverse Logical Problem (3)

Ladd's antilogism gives rise to a rule which gives a systematic method for determining conditions inconsistent with certain combinations. Because any given syllogism can be reduced to a syllogism of the form given in Theorem 0.4, one need not blindly invent laws and see if they agree with results.

A bit of historiography (1)

In the earliest review of Ladd's paper, [Anonymous, 1883], no specific mention is made of this result. The (unidentified) reviewer introduces Ladd's new notation, $\vee$ and $\overline{\vee}$, gives its semantics and formation rules, and notes that "with these she is able to write algebraically all the old forms of statement, and to perform the customary operations of symbolic logic with great brevity and facility" [Anonymous, 1883, p. 514].

The singling out of the antilogism as a fundamental contribution is first (as far as I can tell) made by Brown: "when Mrs. Ladd-Franklin has demonstrated that one simple form underlies all syllogism..." [Brown, 1909, p. 304].

A bit of historiography (2)

Shen quotes "the late Professor Josiah Royce of Harvard":

> *There is no reason why this should not be accepted as the definitive solution of the problem of the reduction of syllogisms. It is rather remarkable that the crowning activity in a field worked over since the days of Aristotle should be the achievement of an American woman" [Shen, 1927, p. 60].*

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> *In a newspaper clip "To Get Her Degree Earned Years Ago", Josiah Royce is quoted as describing her thesis work as "the crowning activity in a field worked over since the days of Aristotle". "The [Aristotelian] system was never fully demonstrated until Mrs. Ladd-Franklin worked out the whole method at Johns Hopkins" (The Hartford Courant, February 21, 1926, p. 20) [Pietarinen, 2013, fn. 6].*

20th-century analysis

The result was the ground-breaking discovery involving the reduction of Aristotelian syllogistics into a single formula [Pietarinen, 2013, p. 3, emphasis added] [preprint];

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Assumes (a) we know what "the problem" is, (b) that it was a problem of Aristotle's, (c) that Ladd-Franklin was trying to solve this problem.

What counts as a problem?

- Does a problem have to be recognised as a problem for it to be a problem?
- Did the ‘problem’ that Ladd solved exist through the two millennia in which no one was bothered by it?
- Or did it only become a problem once someone found it problematic?

Concluding remarks

- In her 1883 dissertation, Ladd-Franklin introduced to Boolean algebra a pair of symmetric copula.
- This allowed her to define the "antilogism", an "inconsistent triad" that could be used to represent every valid syllogism.
- People recognised the utility of this representation soon after her work.
- Within 30 years, people made the leap to her formula being a solution to a problem.
- At some point after that, the problem attributed to Aristotle was attributed as a problem to all intervening logicians, too.
- While she solved a problem, it certainly wasn't Aristotle's, nor had it vexed people for millennia.
- Instead, it was a problem due to Jevons, that Schröder, Boole, and others had attempted to solve.

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Thank You!