Does Aristotelian logic describe human reasoning? Valid syllogisms and canonical models

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Introduction

The mental models theory (e.g., Johnson-Laird, 2004, 2006, 2010, 2012; Khemlani, Orenes, & Johnson-Laird, 2012, 2014; Khemlani, Lotstein, Trafton, & Johnson-Laird, 2015; Oakhill &Garnham, 1996; Orenes& Johnson-Laird, 2012) is a current cognitive theory that proposes that human reasoning is not based on syntactic inferences from logical forms. According to it, people make iconic models or mental representations that are essentially semantic and refer to all of the possibilities that can be true given a proposition. In this way, the theory acknowledges that its fundamentals come from Peirce (1931-1958). However, an important point of the theory to this paper is that individuals do not always identify all of the models related to propositions. Some of the models are easy to be found and people usually note them quickly. Nevertheless, other models are harder to be identified without certain reflection or effort. This fact explains, for example, why individuals make certain mistakes and why certain inferences are more difficult than others.

As far as I know, the theory is very developed with respect to what is called ‘propositional inferences’ in standard logic, i.e., inferences with not quantified sentences. Regarding quantified expressions, the development is less, but undoubtedly there are works in that way. One of them is that of Khemlani et al. (2015), in which the models easy to be noted are named ‘canonical models’ and the harder models requiring more reflection are called ‘noncanonical models’. Thus, the main goal of this paper is to show that all of the valid categorical syllogisms in Aristotelian logic can be considered to be correct only taking the canonical models proposed by Khemlani et al. (2015) into account. This fact is relevant because, if the mental models theory is right, it means that the theory has clear predictions related to Aristotelian logic, and that it can be said that this logic should be accepted by human beings in a natural and quick way. In other words, if we assume the general theses of the mental models theory, we must also assume, on the one hand, that the human mind can consider the syllogisms of Aristotelian logic to be valid without putting a lot of effort, and, on the other hand, that this logic can describe how human reasoning spontaneously works when faced with inferences with structures akin to those of such syllogisms.

To prove all of this, firstly, I will account for the main ideas of the mental models theory about quantified assertions. Then I will explain the fundamental principles of Aristotelian logic. Finally, I will analyze each of the moods of each of the figures in that logic in order to show that they can be accepted as valid by considering only the canonical models.

The mental models theory and quantified sentences

As said, Khemlani et al. (2015) distinguish the canonical models (i.e., the models easily noted) from the noncanonical models (i.e., the models requiring certain cognitive effort). Their thesis is that, given a quantified expression, individuals think about some semantic possibilities corresponding to that expression. Obviously, such possibilities are models and represent particular situations. A problem is that it can be thought that the number of the models that can be considered by an individual at the same time is limited, since his (or her) working memory and mental abilities are not infinite. Khemlani et al. (2015) expose the procedures that can help identify the appropriate number of models in each case. Nevertheless, to the aims of this paper, it is enough to assume, as convention, the numbers that appear on Khemlani et al.'s (2015) table 1, that is, three models in the case of the canonical models, and three, four, or five models in the case of the noncanonical models. That table includes six types of assertions, but only four of them, those used in Aristotelian logic, are relevant to this paper: affirmative universal assertions, affirmative particular assertions, negative universal assertions, and negative particular assertions. I start with the affirmative universal ones.

An affirmative universal expression is usually said to have this structure:

Every x is y

According to the mental models theory, given such an expression, individuals can quickly think that these three canonical models represent all of the possible situations to which it refers:

x	y
x	y
x	y

Note that the three models stand for the same circumstance: a scenario in which both x and y are true. Thus, in principle, the affirmative universal propositions only cause individuals to consider scenarios in which the two terms of the expression are true. Only after further reflection, they can realize that other situations are possible. In this way, an example of noncanonical models corresponding to the affirmative universal assertions can be, following Khemlani et al. (2015), this one:

x	y
not-x	y
not-x	not-y

The first model is just as the previous ones. However, the other two models show that the individual is now aware that the assertion is also consistent with a situation in which something is not x but it is y, and with a situation in which something is neither x nor y.

Maybe an example with thematic content can be illustrative in this regard. Let us think about this assertion:

Every frog is green

The canonical models refer to three different frogs and indicate that they are all green:

frog	green
frog	green
frog	green

Nonetheless, if the individual puts more effort, he (or she) can note that the assertion allows other possibilities too:

frog	green
not-frog	green
not-frog	not-green

Indeed, the second model shows that something, for example, another animal, can be green and not a frog, and the third one refers to the possibility that something is not a frog and is not green at the same time.

As far as the affirmative particular assertions are concerned, it can be stated that they are those that usually have this structure:

Some x is y

According to Khemlani et al. (2015), the canonical models are in this case:

x	y
x	y
x	not-y

Because all of the x are not y now, the third model expresses the possibility that something being x and not y. But the example of noncanonical models proposed by Khemlani et al. (2015) includes one more possibility:

x	y
x	not-y
not-x	y

As it can be checked, in this example, the individual has noted that at least there is another additional possibility: the case in which something is not x but it is y (the third model).

Based on this, it is not hard to deduce the examples of models (both canonical and noncanonical) attributed by the negative assertions by Khemlani et al. (2015). Let us consider an expression such as this one:

No x is y

That is the structure corresponding to the negative universal assertions and, following Khemlani et al. (2015), its canonical models are as follows:

x	not-y
x	not-y
not-x	y

But, of course, noncanonical models are also possible for this kind of assertion. According to them, an example can be this one:

x	not-y
x	not-y
not-x	y
not-x	not-y

Finally, the negative particular assertions are said to have this structure:

Some x is not y

And Khemlani et al. (2015) indicate that the canonical models of an expression of this type can be:

x	not-y
x	not-y
not-x	y

And they also present, as an example of its noncanonical models, the following:

x	not-y
x	not-y
not-x	y
not-x	y

These are the kinds of quantified assertions that are used in Aristotelian logic. As said, my main aim is to show that all of the valid categorical syllogisms in that logic can be considered to be correct by taking into account just the canonical models. However, before arguing in favor of this idea, it seems to be opportune to expose the general framework of Aristotelian logic.

Aristotelian logic and its valid categorical syllogisms

As it is well known, medieval authors used letters for referring to the types of sentences analyzed in the previous section. Based on the Latin words *afirmo* (I state) and *nego* (I deny), they assumed these equivalences:

-A (the first vowel in *afirmo*): affirmative universal assertions.
-I (the second vowel in *afirmo*): affirmative particular assertions.
-E (the first vowel in *nego*): negative universal assertions.
-O (the second vowel in *nego*): negative particular assertions.

There is no doubt that detailed information on and descriptions of Aristotelian logic are to be found in several good works. Only some of them are clearly, for example, Boger (1998, 2001, 2004), Burnett (2004), Gasser (1991), Johnson (2004), Miller (1938), Parsons (2008), Smith (1991), or Woods and Irvine (2004), but my arguments in this section will be based mainly (although not exclusively) on that of Parsons (2008). Having said that, a first important point about Aristotelian logic is that, as it is also well known, the syllogisms consist of three sentences: two premises and a conclusion. In addition, three elements can be distinguished in the syllogisms: the major term, the middle term, and the minor term. The major term appears in one of the premises and is the subject of the conclusion (from now on, I will refer to this term with the letter ‘s’). The middle term appears in the two premises, but it does not in the conclusion (from now on, I will refer to this term with the letter ‘m’). And the minor term appears in one of the premises and is the predicate of the conclusion (from now on, I will refer to this term with the letter ‘p’). In this way, depending on the places in which s, m, and p are, several figures are possible. According to the classification exposed by Parsons (2008), the forms of such figures are these ones:

-Figure 1 (explained by Aristotle in *AnalyticaPriora I*, 4):

m is p
s is m

Ergo s is p

-Figure 1 (indirect) (explained by Aristotle in *AnalyticaPriora I*, 7):

m is s
p is m

Ergo s is p

-Figure 2 (explained by Aristotle in *AnalyticaPriora I*, 5):

p is m
s is m

Ergo s is p

-Figure 3 (explained by Aristotle in *AnalyticaPriora I*, 6):

m is p
m is s

Ergo s is p

From these figures, Aristotle proposed 19 moods by combining the assertions of the types A, I, E, and O indicated above. Thus, for example, a mood of the first figure can be expressed as follows:

A(m · p)
A(s · m)

Ergo A(s · p)

Where the initial capital letter stands for the kind of quantified assertion (in this case, ‘A’ informs that the assertion is affirmative universal) and ‘·‘ means ‘is’.

Actually, as Parsons (2008) mentions referring to Arnauldand Nicole’s (1662) arguments, there are five more moods. However, I will only focus on those indicated by Aristotle. Such 19 moods were given names in the Middle Age. In particular, Peter of Spain, in his *Tractatus* (or *Summulaelogicales*) presented a number of names that could be learned in a relatively easy way and that provided data about the moods. Those names are the following:

Figure 1: *Barbara*, *Celarent*, *Darii*, and *Ferio*.
Figure 1 (indirect): *Baralipton*, *Celantes*, *Dabitis*, *Fapesmo*, and *Frisesomorum*.

Figure 2: *Cesare*, *Camestres*, *Festino*, and *Barocho*.
Figure 3: *Darapti*, *Felapto*, *Disamis*, *Datisi*, *Bocardo*, and *Ferison*.

Nevertheless, what is interesting for the goals of this paper is that the names show the forms of the moods. The first three vowels of each mood correspond to the types of quantified assertions included in it. Thus, the first vowel indicates the type of quantified assertion corresponding to the first premise, the second one indicates the type of quantified assertion corresponding to the second premise, and the third one indicates the type of quantified assertion corresponding to the conclusion. In this way, for example, the structure of *Celarent* is this one:

E(m · p)
A(s · m)

Ergo E(s · p)

These are the basic notions of Aristotelian logic that are relevant and that need to be taken into account to achieve the aims of this paper. As said, I have based my description on the version of it proposed by Parsons (2008) and I will continue to do that in the following pages. As also mentioned, my main goal is to show that just the canonical models presented by Khemlani et al (2015) enable to consider the valid categorical syllogisms (i.e., Aristotle's 19 moods) to be correct without the need to make a further effort. I will try to do that in the next sections, each of which is devoted to a figure.

The figure 1 and the canonical models

The first mood of this figure is *Barbara*. Really, its form has already been presented above. It is this one:

A(m · p)
A(s · m)

Ergo A(s · p)

According to the framework based on the mental models theory proposed by Khemlani et al. (2015), the canonical models of the first premise are:

m p

m	p
m	p

But, given that the second premise states that s is not possible without m, the previous scenarios can be completed in this way:

m	p	s
m	p	s
m	p	s

Thus, these three models include the information provided by the two premises (that whenever m is true, p is true too, and whenever s is true, m is true as well), and, according to the canonical models, no more information can be considered. Therefore, what needs to be checked now is whether or not the information given in the conclusion is consistent with the previous three scenarios. It is easy to do that because what the conclusion means is that it is not possible a scenario with s and without p, and, as it can be observed in the previous models, there is no such a scenario. In all of them, if s happens, p is also present.

The structure of *Celarent* has been indicated too. It is as follows:

$E(m \cdot p)$
$A(s \cdot m)$

Ergo $E(s \cdot p)$

Now, the models of the first premise are:

m	not-p
m	not-p
not-m	p

And the information of the second one is that it is not possible s without m. So, in this case, it is allowed adding s to the models in which not-m is not:

m	not-p	s
m	not-p	s
not-m	p	

In this way, the conclusion is also correct in this case because it states that no s is p and, in the previous models, any scenario in which both s and p are true cannot be found.

On the other hand, the structure of *Darii* is:

A(m · p)
I(s ·m)

Ergo I(s · p)

The canonical models of the first premise are now:

m	p
m	p
m	p

Nevertheless, if the information contained in the second one is taken into account, because it indicates that there can be a case in which s happens and m does not, it is necessary to add a new model:

m	p	s
m	p	s
m	p	s
not-m		s

But this does not make the conclusion incorrect because it only states that there are cases of s and p and, as it can be checked, there are such cases.

Finally, the form of *Ferio* is:

E(m · p)
I(s · m)

Ergo O(s · p)

The first assertion leads to these possibilities:

m	not-p
m	not-p

not-m	p

But, because the canonical models of I indicate two situations in which both terms occur and one situation in which the first term appears and the second one does not, it is only necessary now to add a ‘s’ to each model:

m	not-p	s
m	not-p	s
not-m	p	s

And the conclusion is correct again, since it only states that there are cases of s and not-p, and we have two of those cases.

The figure 1 (indirect) and the canonical models

The structure of *Baralipton*is obviously as follows:

A(m · s)
A(p · m)

Ergo I(s · p)

Thus, the canonical models of the first premise are:

m	s
m	s
m	s

Because the second one is also a sentence of type A, it is only necessary to add p to each scenario:

m	s	p
m	s	p
m	s	p

Therefore, the conclusion is consistent with these models. It claims that there are cases of s and p, and the models show that that is so in all the possibilities.

A second mood of this figure is *Celantes*:

E(m · s)
A(p · m)

Ergo E(s · p)

In this way, the models of the first assertion are as follows:

m	not-s
m	not-s
not-m	s

On the other hand, the second premise provides the information that p is not possible without m. So, p only can be added in the scenarios in which m is true:

m	not-s	p
m	not-s	p
not-m	s	

And, because the conclusion says that s is impossible with p, and, in the only scenario in which s is, p is not, the conclusion is valid here as well.

Another mood is *Dabitis*, and its form is, evidently, the following:

A(m · s)
I(p · m)

Ergo I(s · p)

The canonical models of the first assertion are:

m	s
m	s
m	s

And, given that the second one is affirmative particular, it is necessary to include a case of p without m:

m	s	p
m	s	p
m	s	p
not-m		p

And, since p appears in all of the cases in which s also appears, there is no doubt that the conclusion is correct here too.

The following is *Fapesmo*, which has this structure:

A(m · s)
E(p · m)

Ergo O(s · p)

The canonical models of the first premise continue to be the same:

m	s
m	s
m	s

But the second one states that no p is m. Therefore, because in these three models m appears, it is necessary to add not-p to them. However, in addition, it is also necessary to include cases of p and not-m. Thus, the result is:

m	s	not-p
m	s	not-p
m	s	not-p
not-m		p
not-m		p

Nevertheless, the conclusion only requires s and p not to be together, which occurs in all of the possibilities.

The last mood is here *Frisesomorum*, and its name, as in all of the other cases, reveals its form:

I(m · s)
E(p · m)

Ergo O(s · p)

The canonical models corresponding to the first sentence are, of course:

m	s

m	s
m	not-s

Nonetheless, the second one is of type E, which means that in all of the models with m only not-p is possible, and that the cases of not-m must be added:

m	s	not-p
m	s	not-p
m	not-s	not-p
not-m		p
not-m		p

The conclusion only claims that there are cases of s and not-p, and as it can be checked, that is what happens in the two first models. Therefore, this mood is coherent with the canonical models proposed by Khemlani et al. (2015) as well.

The figure 2 and the canonical models

As indicated, the first mood of this figure is *Cesare*. So its form is the following:

E(p · m)
A(s · m)

Ergo E(s · p)

Thus, the canonical models of the first premise are these ones:

p	not-m
p	not-m
not-p	m

However, the second premise informs that s is only possible when m happens too. s hence can be added only in the third model:

p	not-m	
p	not-m	
not-p	m	s

And these scenarios allow checking that, indeed, as the conclusion says, there are not cases of s and p.

The second mood is *Camestres*. So its structure is this one:

A(p · m)
E(s · m)

Ergo E(s · p)

Therefore, the first sentence has the canonical models corresponding to the affirmative universal assertions, i.e.,

p	m
p	m
p	m

But, given that the second one is a negative universal assertion, it is necessary to add certain data. Firstly, models in which s is true and m is false must be included. Secondly, it is also required to indicate that, when m happens, it is only possible not-s. In this way, the result is as follows:

p	m	not-s
p	m	not-s
p	m	not-s
	not-m	s
	not-m	s

Nevertheless, the two last models can be completed. The first premise informs that, if p occurs, m has to occur too. So, this update of the models is correct:

p	m	not-s
p	m	not-s
p	m	not-s
not-p	not-m	s
not-p	not-m	s

The final result hence is that, as stated by the conclusion, in the situations in which s happens, it cannot be accepted that p happens at the same time.

Another mood of this figure is *Festino*, and this name leads us to this form:

E(p · m)
I(s · m)

Ergo O(s · p)

If we think about the canonical models of the first premise, we can say that they are these ones:

p	not-m
p	not-m
not-p	m

The second one states that some s is m. Therefore, it allows two possibilities: i) both s and m are true, and ii) s is true and m is false. Thus, a way of updating the previous models is to add s to all of them, whether m is in them or not:

p	not-m	s
p	not-m	s
not-p	m	s

And, as it can be noted, this makes the conclusion true, since it shows that, indeed, there is at least a case of s and not-p (the last model).

The final mood of the second figure is *Barocho*, and its structure is:

A(p · m)
O(s · m)

Ergo O(s · p)

Obviously, as in the case of *Camestres*, the first sentence leads us to these canonical models:

p	m
p	m
p	m

But the second one is a negative particular assertion, which means, on the one hand, that it is necessary to add cases of not-m (in which s is true), and, on the other hand, to include not-s in the cases in which m happens:

p	m	not-s
p	m	not-s
p	m	not-s
	not-m	s
	not-m	s

Nevertheless, for reasons akin to those indicated for *Camestres* (p is only possible if m is true), the last two models can be updated here as well:

p	m	not-s
p	m	not-s
p	m	not-s
not-p	not-m	s
not-p	not-m	s

And the result is that the conclusion of this mood is clearly valid because there are cases in which s happens and p does not (the last two models).

The figure 3 and the canonical models

As indicated, this is the last figure that I will analyze in this paper, and its first mood is *Darapti*. As in the previous cases, the name reveals its structure:

A(m · p)
A(m · s)

Ergo I(s · p)

And this structure implies that the canonical models of the first assertion are the following:

m	p
m	p
m	p

The second sentence, on the other hand, indicates that s has to be included in all of these models, since m appears in all of them:

m	p	s
m	p	s

m	p	s

So, the conclusion is true because some s are p (in fact, all of them are).

The next mood is *Felapto*, i.e., a mood with this form:

E(m · p)
A(m · s)

Ergo O(s · p)

The first models are therefore as follows:

m	not-p
m	not-p
not-m	p

Nonetheless, the second premise claims that cases of m without s are not possible and that these models hence describe better the possible scenarios:

m	not-p	s
m	not-p	s
not-m	p	

Evidently, the fact that m does not happen in the third model can lead us to add not-s in it. However, it is obvious that the two first models show that the conclusion is true: there are cases in which s occurs and p does not.

Another mood corresponding to this figure is *Disamis*, whose structure is clearly:

I(m · p)
A(m · s)

Ergo I(s · p)

So, the canonical models of the first premise are now:

m	p
m	p
m	not-p

And the second premise causes s to be included in all of the models, since m is true in all of them:

m	p	s
m	p	s
m	not-p	s

Thus, these possibilities show that the conclusion is correct, since there are cases of s and p (the first one and the second one).

The fourth mood of the third figure is *Datisi*, and its form hence is:

A(m · p)
I(m · s)

Ergo I(s · p)

This means that the first sentence refers to these canonical models:

m	p
m	p
m	p

And, because m appears in the three cases, the models of the second premise can be considered by including s in the two first possibilities and not-s in the last one:

m	p	s
m	p	s
m	p	not-s

In this way, its conclusion is also absolutely correct. The reason is the two first models, which show that some s are p.

Bocardo is also a model of this figure. As its name reveals, its structure is:

O(m · p)
A(m · s)

Ergo O(s · p)

The negative particular assertion that appears in the first premise leads us to these models:

m	not-p
m	not-p
not-m	p

And the affirmative universal assertion that appears in the second one leads us to add s in all the cases in which m is true:

m	not-p	s
m	not-p	s
not-m	p	

So, it can be noted that there are cases of s and not-p (the two first possibilities), and that that fact means that the conclusion is correct.

Finally, the last model is *Ferison*, which has this form:

E(m · p)
I(m · s)

Ergo O(s · p)

The canonical models of its first premise are:

m	not-p
m	not-p
not-m	p

Thus, the models of its second premise can be taken into account by including s in the scenarios in which m happens, and by adding another scenario in which m is true and s is not:

m	not-p	s
m	not-p	s
not-m	p	
m		not-s

Again, the two first premises show that the conclusion is true, since they reveal that, indeed, some s are not p. In this way, it can be said that all of the moods analyzed in this paper can be accepted following the mental models theory, and, in particular, following just the canonical models proposed by Khemlani et al. (2015).

Conclusion

The precedent pages provide important consequences for the study of the human mind if the mental models theory is assumed. Given that the conclusions of all of the reviewed moods can be drawn by using just the canonical models indicated by Khemlani et al. (2015), it can be stated that Aristotelian logic presents a set of inference schemata that are natural for human reasoning. By this, I mean that, because the valid categorical syllogisms of that logic can be considered to be correct by taking only the canonical models into account, according to the mental models theory, human beings should accept such syllogisms in a quick way and without making further cognitive effort. Thus, it can also be stated that those syllogisms can be very useful for explaining, describing, and even predicting the results of the reasoning tasks in which they are involved.

This point is relevant because, as it is well known, the same cannot be said about standard logic and the natural deduction calculi (see, e.g., Gentzen, 1935). Indeed, the literature on cognitive science shows that there are several situations in which simple principles, rules, or requirements of standard logic are not followed or fulfilled by people (see, e.g., Orenes& Johnson-Laird, 2012). Apart from that, another problem of that logic is that, when it addresses quantified assertions (for example, when first-order predicate calculus is used), it resorts to very complex formulae, and it is unclear which the mental process why individuals make or construct those formulae could be (see, e.g., López-Astorga, 2014).

But the mental models theory seems not to have these problems. In almost all of the books, chapters, and papers related to it, one might check that this theory can account for and predict many of the results offered by participants in reasoning tasks that standard logic or theories more or less based on that logic cannot explain. Furthermore, given that logical form is not relevant for the mental models theory, which is essentially a semantic approach (see, e.g., Johnson-Laird, 2010), the problem of the translation of individuals' mental representations into 'well formed formulae' does not exist in that framework.

But the most important finding of this paper can be that the mental models theory can prove that it is worth continuing to consider Aristotelian logic. If the precedent arguments are right, it is obvious that Aristotelian logic is not obsolete, that it has cognitive value, and that it can be very useful to describe and make predictions about human inferential activity. In this way, it could be very interesting that the proponents of the theory checked empirically and experimentally arguments such as those proposed here, and that they designed experiments using Aristotelian valid syllogisms in order to review whether or not my analysis in this paper and, of course, their theses on quantified assertions are correct. And I am saying this because, at least as far as I know, such a work is not made at present. In any case, a point seems to be absolutely clear: the use of the main theses and the methodology of the mental models theory can be very helpful in checking whether or not the logical theories of the past continue to be somehow applicable tools today.

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Summary

Does Aristotelian logic describe human reasoning? Valid syllogisms and canonical models

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In the case of quantified propositions, the mental models theory distinguishes between canonical and noncanonical models. While people identify the canonical models in an immediate, rapid, and easy way, the noncanonical models cannot be detected without reflection and cognitive effort. In this paper, I try to show that all of the valid syllogisms in Aristotelian logic can be considered to be correct by resorting only to the canonical models of their sentences. In this way, I argue that this means that Aristotelian logic can be a useful criterion to explain, describe, and even predict people's conclusions from quantified assertions.

Keywords: Aristotelian logic, mental model, quantification, reasoning, syllogism