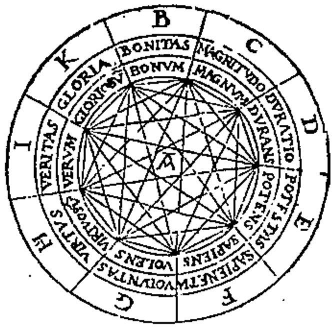

Lógica e Filosofia da Ciência

Editado por
Olga Pombo e Ángel Nepomuceno

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Faculdade de Ciências da Universidade de Lisboa,
Campo Grande, Edifício C4, 3º Piso, Sala 4.3.24
1749-016 Lisboa, Portugal
http://cfcul.fc.ul.pt
cfcul@fc.ul.pt

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Simultaneamente, discutimos o carácter *intensional* da nova noção. Tecnicamente, esboçamos a demonstração do teorema de William Howard (1973) que mostra que o axioma da extensionalidade não tem uma interpretação *dialectica*. Observa-se que o argumento de Howard é válido em circunstâncias muito gerais baseando-se, fundamentalmente, no facto de que todo o termo fechado do sistema de Gödel é *majorizável*. No ensaio também se discutem brevemente as hesitações intelectuais de Gödel que o levaram, durante oito anos, a estar indeciso sobre a eventual publicação de uma tradução inglesa do seu artigo. Passados estes oito anos, a tradução não se materializou.

A segunda parte do ensaio aborda aplicações recentes da interpretação *dialectica* à análise de demonstrações matemáticas (via a extracção de informação de natureza computacional). Estas aplicações estão baseadas numa modificação da interpretação de Gödel (que usa ainda as transformações sintácticas de Gödel), a denominada *interpretação funcional monótona* de Ulrich Kohlenbach (1993). Nesta interpretação, a noção de funcional majorizável desempenha o papel central. Descrevemos o programa de Teoria da Demonstração *aplicada* (em especial à Análise Funcional Numérica), conhecido por *Proof Mining*, comentando os seus sucessos e benefícios. Na parte final do ensaio, discutimos uma recente interpretação funcional, a *interpretação funcional limitada* do autor deste sumário em colaboração com Paulo Oliva (2005). Esta nova interpretação funcional baseia-se numa transformação sintáctica distinta da de Gödel e que «age como se» todo o funcional fosse majorizável. Mostramos como os resultados teóricos de Kohlenbach se podem ver, de uma forma muito perspícua, à luz desta nova interpretação.

A interpretação *dialectica* de Gödel envelheceu muito bem nestes cinquenta anos. Acreditamos que ainda não foi dada a última palavra sobre os seus méritos fundacionais e que as suas potencialidades (e as de interpretações semelhantes) ainda não estão cabalmente compreendidas.

LIMITATIONS OF THE PREDICATE CALCULUS.
THE CASE OF DONKEY SENTENCES

María J. Frápolli
Departamento de Filosofía I
Universidad de Granada

1. El contexto general

That the first order predicate calculus has its shortcomings when applied to the complexities of natural languages is no news. This is the background in which extended and non-standard logics find their rationale. But besides adding new operators or rejecting some of the rules governing them, there are deeper ways of contesting the logical path that the predicate calculus has converted in the paradigm of logical reasoning. Showing that the complexities of natural languages will require finer and more flexible methods of analysis than those allowed by the standard predicate calculus will be one of the aims of this paper. Nothing new under the Sun. Logicians, linguists and philosophers in the last century has overtly defended or covertly suggested that a change would be desirable.

Our purpose here will be to illustrate the need of a new look at the logical features of natural languages focusing on a set of examples, the so-called "Donkey sentences", particularly reluctant to analysis. The trademark of donkey sentences is the co-existence of logical operators, i.e., connectives and quantifiers, together with anaphoric links among singular terms. The main difficulty for a suitable analysis, capable of being smoothly accepted by the varied group of theories that have risked a proposal, lies in the issue of the identification of the operators (and operations) involved and their relative scope.

We will use Donkey sentences to illustrate a general proposal about conditionals. Conditionals, as second-order binary operators, should be understood, we will maintain, as some kind of quantifiers. When there is no adverbial operator that modifies its force, conditionals are general quantifiers ranging over sets of situations. When adverbially modified, the quantifier might cease to be a general quantifier and turn into one of the non-standard weaker quantifiers, "most", "a few", "seldom", and in the limit case of negation, it becomes an existential quantifier. Conditional sentences are thus quantified sentences, and the adverb "then" that usually lies implicit in the consequent clause works as an anaphoric pro-noun, although from a logical point of view we should say an anaphoric "pro-adverb", which is linked to its head, the general (conditional) quantifier. This way of looking at conditional logic, i.e., considering the conditional particle if as a universal quantifier with the meaning of "in every (some, almost all, etc.) situation" and interpreting the particle then as an anaphoric pro-adverb pointing to the situation at issue, allows to take a fresh look at the problem of Donkey sentences.

2. Donkey Sentences: A Study Case

Donkey sentences were introduced in the philosophical debate by Peter Geach in the sixties (Geach 1962: 155-156) and, since then, they have been a field in which every theory of quantifiers and pronouns in natural languages tests their merits. Although Donkey sentences are primarily used to illustrate (and explain) the mechanism of anaphora, we will not focus on this referential operation, but will be interested in the identification of the operators (connectives and quantifiers) in the logical form behind this kind of sentence.

Examples of Donkey sentences are:

(1) If Pedro has a donkey, he beats it,
(2) When a farmer owns a donkey, he beats it,
(3) Always that a farmer owns a donkey, he beats it now and then.

Examples (1) and (2) are the classical cases, and example (3) is a more complex version due to D. Lewis (1975).

One of the pervasive difficulties listed in the bibliography has been explaining why, for a question of scope, (1) cannot be translated as

(1.a) $\exists x$ [(Donkey (x) & Owns (Pedro, x)) $\rightarrow$ Beats (Pedro, x)]

This rendering is inappropriate because it would give priority to

the existential quantifier over the conditional, converting (1) in an existential claim, which it is not.

The alternative option (1.b),

(1.b) $\exists x$ (Donkey (x) & Owns (Pedro, x)) $\rightarrow$ Beats (Pedro, x),

i.e., giving the conditional wider scope, would leave the variable in the consequent clause unbound and thus convert it in an open formula, which it is not either,

To overcome this difficulty, it has been a common place to translate (1) using a general quantifier instead, as in (1.c),

(1.c) $\forall x$ [(Donkey (x) & Owns (Pedro, x)) $\rightarrow$ Beats (Pedro, x)].

Regarding (1.c), a point of discomfort has been how (and why) the expression "a donkey" is now translated using a general quantifier, whereas in narrower contexts, like (1.d),

(1.d) Pedro owns a donkey,

it would have been understood as involving an existential quantifier binding the variable that accompany the monadic first order predicate, as it happens in (1.e), the standard translation of (1.d),

(1.e) $\exists x$ [(Donkey (x) & Owns (Pedro, x)].

To illustrate the debate behind the difficulties listed above, it will be enough to recall the treatment of donkey sentences in three major contemporary theories: Dynamic predicate logic (DPL), Game theoretical semantics (GTS) and Discourse representation theory (DRT).

The ideas behind DPL and GTS are similar and consist in distinguishing two notions of scope (GTS) or of binding (DPL), which in this case amounts to the same, although the general differences between the two views are notorious. While DPL sticks to the Principle of Compositionality (and prides itself on it), GTS rejects the principle as a general *desideratum* of any semantic theory. The Principle of Compositionality cannot be maintained together with the branching quantifiers that are characteristic of GTS. DPL and GTS also share their shortcomings, being both unable to explain the mechanisms behind anaphoric links when the head is either in a general or a negative sentence.

GTS denounces that the notion of scope that we use in our standard *calculi* embodies, in fact, two different notions that answer for different relations among the ingredients of propositions. One of them accounts for the relations of logical priority among logical operators, the other accounts for the binding scope of quantifiers. In complex cases like those of Donkey sentences, the two scopes do not go together and hence the translation problems into a *calculus* that, like standard first order *calculus*, does not make room for the distinction. With roughly the same range of problems in mind, DPL introduces two kinds of binding for variables. An occurrence of a variable in a formula can be free in the standard sense, if from a syntactical point of view it lies outside the scope of quantifiers in the formula, while anaphorically referring to some of these quantifiers that acts as the head of the anaphora. These variables would be, using Sandu' s terminology (Sandu 1997), syntactically free but semantically bound to their head. Bifurcation, in scope or binding respectively, is meant to differentiate the logical priority of operators, that in Donkey sentences like (1)-(3) correspond to the conditional over any quantifier, from the scope of quantifiers that have to reach all variables in the formula. DPL would render (1) as (1.b), and GTS would use its two-dimensions language to display the independence of both tasks.

An interpretation of a sentence in DRT is a set of referential markers and conditions. This set is called "a Discourse Representation Semantics" (DRS). Referential markers are singular terms, and conditions are formulae that the individuals referred to by the referential markers have to satisfy. A DRS for (1) would be something like the following:

(DRS.1) (a, b, donkey (b), beats (a, b)),

where "a" and "b" are referential markers, corresponding to "Pedro" and "a donkey", and the rest are conditions on them. Although DRT would interpret (1.d) as (1.e), it would treat (1) as if it had a structure similar to (1.c), with a universal quantifier. These

treatment (see, for instance, van Eijck & Kamp, 1997) needs to assume that the logical role, and then the operator behind, of indefinite descriptions, as "a donkey", vary depending on context, having sometimes the import of a universal quantifier, sometimes that of an existential quantifier.

Keeping track of what has been said so far, donkey sentences, while perfectly grammatical and admissible sentences, pose translation difficulties that reflect difficulties in understanding the logical ingredients of propositions expressed and the relations among them. These difficulties have required modifications of the standard notions of scope or of binding, or else making of indefinite descriptions context-dependent expressions in an unusual way.

3. Conditionals as General Quantifiers

The background picture behind the new look at Donkey sentences that we would like to defend here can be summarize, in a nutshell, in the idea that unmodified[1] conditionals are instances of universal quantifiers (*if* as an instance of $\forall$) and that quantifiers have, in natural languages, an intra-linguistic, non-representational, inferential, import. Making the first claim more precise, conditionals are, if they have to support an inferential interpretation, irreducible[2] n-ary devices, n >1. For the second claim we will not argue in this paper although it would be needed to bring into the mind a couple of the consequences of it. One of them is that we reject the common objectual interpretation of quantifiers, its restriction of only allowing nominal variables and, with it, the connection between quantification and ontology. Another one is that quantified sentences do not have primarily the role of representing reality; they rather display inferential connections from the speaker's point of view. Its role is not to be used to express propositions and thus they can be said to be true or false only in a derivative way. Some effects of these consequences will be patent in the interpretations of Donkey sentences in section 4

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[1] By "unmodified" we understand conditionals in which no expressions occur that constraint the force of the universal quantifier. Some adverbs, like "usually", "often", "seldom" etc. indicate that the quantifier at issue is weaker than generality.

[2] In the sense explained by Keenan (1987).

below.

The picture that we favor has to be distinguished from two views on conditionals that might appear quite similar. One is the interpretation of conditionals as generalized quantifiers (Barwise and Cooper 1981). The other one is the deductive view of conditionals. Generalized quantifiers are relations among sets of individuals. And they are true when the specified relations among the sets involved hold. Our view understands conditionals as intra-linguistic devices that display permissions to infer propositions under particular circumstances. The deductive view on conditionals roughly upholds that, in conditionals, the information in the consequent follows, in a logically valid inference, from the information in the antecedent together with some added premises. This view is too strong and also takes a wrong perspective. It amounts to saying that a conditional is true when the consequent is true in all models in which the antecedent, together with the relevant premises, is true. It takes a model-theoretical, external, perspective. In our view a conditional is neither true nor false, they do not represent situations but rather have the import of authorizations of informational transfer contextually constrained.

In his (1984), van Benthem initiated a research program on conditional logic. Conditional logic is the logic of conditional statements. Van Benthem begins his paper with the following words: "Conditional statements occupy a central place in reasoning, and hence their proper analysis is a principal task of logic" (1984:303). Van Benthem´s main claim about conditional statements and its logic is that "if" works as a generalized quantifier, as a function connecting sets of antecedent and consequent "occasions", as he says. Notice that van Benthem's thesis is that "if" works as a generalized quantifier, i.e., as a determiner that expresses a relation between sets of individuals. What we want to put forward here is that *if* is a general (not necessarily unrestricted) quantifier, interpreted as an inferential device of transference of information. Backgrounds behind van Benthem's position and ours are quite divergent, although we are applying his insights to develop a stronger thesis. The stronger thesis is that, in natural languages, *if* and *all* perform the same task, being the difference between them one in the range of the "entities" quantified over. Conditionals are universal quantifiers ranging over sets of situations, circumstances, models or possible worlds — every one chooses their favorite theory. Thus, *if* is an instance of *all* for the case of situations (or your favourite alternative). The accompanying particle "then" works, on van Benthem's view that we borrow, as an anaphoric pronoun bound by the universal quantifier. Van Benthem wants to keep *if* as a separate quantifier, with its own peculiarities, and others (Lapierre (1996), for instance) have followed this general path, characterizing *if* as one among the general class of Generalized Quantifiers. Lapierre (1996: 237-8), nonetheless, actually identifies what he calls a "conditional relation" with the quantifier "all". From the point of view of its formal properties, one might want to characterize a minimal conditional logic, and to continue then adding axioms to cover a wider range of determiners. Nevertheless, if the aim is the meaning of natural language expressions, all these subtleties are inapplicable. This thesis on natural languages does not diminish in the least the interest of van Benthem's project for formal semantics.

4. Back to Donkey sentences

With a view on conditionals as general quantifiers, the structure of Donkey sentences can be displayed in a systematic, straightforward way that also explains the difficulties, and other alternative ways of solution, like those of GTS, DPL, and DRT.

All these proposals agree in that the conditional in (1)-(3) has the logical priority over the quantifiers. And they are right. GTS signals it making the conditional independent of the quantifier. DPL establishes the priority of the conditional maintaining the variables in the consequent syntactically free (although semantically bound by the existential quantifiers) and DRT eliminates the existential quantifiers altogether. DRT is (accidentally) closer to our view in that it acknowledges the occurrence of a general quantifier. But, contrary to DRT' s explanation, the universal quantifier in (1.c) does not translate the indefinite noun phrase "a donkey" that, even in this context, has an existential quantifier at its logical form, but the conditional particle *if*, which is a universal quantifier on its own, ranging over sets of situations. This universal quantifier has indeed the logical priority in (1). Thus, those who have felt that there were a general quantifier with wider scope were right: the *if* quantifier. But also those who have felt that there must be an existential quantifier with narrower scope are right, although related to a different logical ingredient. In fact, there are at least two quantifiers at work in the simplest Donkey sentence, the universal *if* quantifier which has the logical priority and the usual existential quantifier that falls under the scope of *if*. The quantifiers in (1) are thus (a) a universal quantifier translating the conditional particle *if*, meaning "in all situations s", and having the logical priority, and (b) an existential quantifier related to the indefinite description "a donkey". There also are three anaphoric links, one related to the pronoun "it" which is a variable bound by the existential quantifier that occurs in "a donkey", another related to the pronoun "he" which head is the proper name "Pedro", and still another related to the (implicit) *then* particle which also is a variable bound by the universal quantifier signaled by the *if* particle. Then a better translation of (1) into a semiformal language that discloses its logical structure would be (1.f),

> (1.f) $\forall s\ [\exists x\ (\text{In } s, \text{Donkey } (x)\ \&\ \text{In } s\ \text{Owns } (\text{Pedro}, x));\ \text{In } s\ \text{Beats } (\text{Pedro}, x)]$.

Syntactically "in s" is an adverbial phrase, and from a logical point of view is a circumstance shifting operator.

Donkey sentences are much more complex than that, and it is no wonder that they have deserved the enormous amount of ink and paper already devoted to them. We have already listed the *if* quantifier, the existential quantifier, and the three anaphoric links marked respectively by "then", "he" and "it". The anaphoric links cannot be completely characterized as repeated bound variables[3], but require their own operator, what adds three more operators to the logical form of (1). The total sum will be five higher-order functions, which explain the difficulties enclosed in this kind of examples.

With this analysis in mind, let us go back to examples (2) and (3) and see how it behaves. Example (2) above,

> **(2)** When a farmer owns a donkey, he beats it,

adds a new existential quantifier to the logical form of (1) corresponding to the indefinite description "a farmer". This quantifier also falls under the scope of the universal conditional operator. Thus, a translation of (2) into a semiformal language would be something like,

> (2.a) $\forall s\ [\exists xy\ (\text{In } s, \text{Donkey } (x)\ \&\ \text{In } s, \text{Farmer } (y)\ \&\ \text{In } s, \text{Owns } (y, x));\ \text{In } s, \text{Beats } (y, x)]$.

Example (3) poses an interesting challenge. Lewis uses it to discuss the range of the quantifiers involved, and says that in most interpretations, (3) will express a contradictory proposition due to the divergent meanings of "always" and "now and then". Independently of the weight we give to Lewis' conclusion, our proposed account of conditionals as quantifiers will explain why (3) is not contradictory, although it is somehow paradoxical in the sense that the adverb "always" does not add anything to the content. (3),

> **(3)** Always that a farmer owns a donkey, he beats it now and then, is only a stylistic variant of (4),
> **(4)** When a farmer owns a donkey, he beats it now and then.

In both cases, "always" and "when" signal the presence of a universal rule, and the users of (3) and (4) are displaying their beliefs about all situations of a certain kind. They are all those situations in which there is (at least) a farmer, (Fx), and (at least) a donkey, (Dy), and in them the farmer beats the donkey now and then. Whereas "always" or "when" encode sets of situations, "now and then" talk about instants of time. No contradiction then, although the contradiction obviously rises if, as happens in every standard analysis, "always" and "now and then" are interpreted as sharing their range. (4) would have a structure such as (4.a)

> (4.a) $\forall s\ [(\exists x)\ (\exists y)\ (\text{In } s\ \text{Donkey } (x)\ \&\ \text{In } s\ \text{Farmer } (y)\ \&\ \text{In } s\ \text{Owns } (x, y);\ \exists t\ (\text{In } s\ \text{Beats } (x, y, t))]$.

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[3] A promising way of treating anaphoric links is using a second order quantifier-like identity operator, as the one used by Williams (1989). An alternative, and equivalent, way is using Geach's reflexivity operator, (Geach 1962). A treatment of anaphora using a strategy close to Geach's operator can be found in Böttner (1992), and he draws the idea back to Suppes (1974) and Keenan (1987).

Our paraphrases do not belong to the predicate logic. Subformulas in (2.a), (1.f) and (4.a) are connected by a semicolon ";", which is not a connective of any standard calculus (and for which we have not given a definition). The reason lies outside the topic of the interpretation of conditionals as quantifiers, although it falls in the middle of the intra-linguistic, non-representational interpretation of quantifiers that, in our view, acts as general background.

Quantified sentences do not express truth bearers, because their role does not consist in representing states of affairs. They do not express propositions and cannot be fully translated in a linear, static notation. Among the varied formal proposals in the semantic arena, DRT and Situation Semantics are probably the most appropriate systems.

Donkey sentences also provide with examples in which apparently the Principle of Compositionality fails. From the point of view taken here, the reason of this failure is not the presence of complex anaphoric relations. The Principle of Compositionality simply does not apply, because what we reach after having processed a Donkey sentence is a complex network of inferential permissions and prohibitions. Exactly the same situation we encounter any time that there are quantifiers – in fact any kind of second order logical operators – at work. The playground of the Principle of Compositionality is the practice of expressing propositions. This is not the case when quantifiers are been used. At this point I remember Ramsey's words: "Many sentences express cognitive attitudes without being propositions; and the difference between saying yes or no to them is not the difference between saying yes or no to a proposition" (1931: 237-238). Conditional sentences are of this kind, they open restricted paths to transport information from some situations to others. They do not describe the world around but in their barest form show the speaker's inferential network.

In trouble-free examples, for uncomplicated semantic questions, the formal options that one chooses are, for most purposes, quite irrelevant, even if the philosophical backgrounds that support them are not subtle enough to undertake the task of analysing natural languages. But Donkey sentences are not interpreters-friendly. They resist any approach that does not incorporate the appropriate tools and perspectives. This proof-resistant nature is one of the sources of the success of Geach's examples, and a reliable guide for sharpening our analytical equipment. Understanding conditionals as general quantifiers seems to pass the test. This is not its only merit, but we believe that it is at least a reason to attentively consider this proposal.

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SISTEMAS EXPERTOS Y LINGÜÍSTICA COMPUTACIONAL: ESTRUCTURAS LÓGICO LINGÜÍSTICAS DE LENGUAS ANTIGUAS[*]

Cristina Barés Goméz

Abstract. This article discusses some of the problems regarding ancient semitic languages research when using computational tools. Computational Linguistics and Expert Systems implemented in hermeneutics methodology formalize a natural language better than classical methodologies.

1. Formalizaciones lógico-lingüísticas.

Los distintos avances en las lógicas matemáticas en los últimos años nos permiten acercarnos a diferentes formas de argumentaciones correctas. Las lógicas modales y la reciente lógica difusa (Trillas 1995) permiten abarcar un mayor espectro de las apreciaciones formales, pues ya no nos reducimos a los únicos valores de verdadero y falso. Ello nos permite continuar las diferentes investigaciones acercándonos cada vez más a la determinación formal del pensamiento mediante la resolución de problemas en ámbitos determinados. No podemos optar por una formalización completa que se asemeje al lenguaje natural, como ya demostró Gödel, pero mediante el estudio de los diferentes aspectos situados en problemas concretos podemos "hacer camino al andar".

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