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The meaning of *there* in existential sentences and the logic of natural languages

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Aim: to demonstrate that **purely linguistic investigations can pave the way to discovering the logic (or at least, one of the logics) underlying the structure of natural languages.**

Three main parts:

1. The linguistic part:

The definiteness effect in existential sentences

a) The meaning of the *there*-element in existential sentences

b) The derivation of the definiteness effect

2. The logical part:

Combinatory logic

a) Combinators as operations on functions

b) Typed combinators

c) Types and implicational logics

3. Putting together

Natural languages and the logic of the {B, C, I, W} base

1. The definiteness effect in existential sentences

1.1. Data and terminology

(1) There are <u>some</u> <u>lizards</u> <u>in the garden</u>.
<u>Det N</u> <u>PP_{loc}</u>

The structure of the data examined here:

(2) *there are* <u>Det N</u> <u>PP_{loc}</u>
pivot coda

McNally (2008) identifies existential *there*-sentences on the basis of ***two main criteria***:

The syntactic criterion:
The existential construction is ***special*** in any language; compare (1) with the ***canonical*** sentence form in (3):

(3) *Some lizards are in the garden.*

The semantic criterion:

The statement an existential sentence expresses cannot entail anything other of the entities the pivot nominal denotes than their ***mere existence or presence somewhere.***

This criterion rules out all there-sentences containing a non-existential main verb.

The two criteria should be present **simultaneously** in order to set apart existential *there*-sentences

a) from the truly locative *there*-sentences:

(4) *There stood in the corner an empty coat rack and umbrella stand.*

b) from the canonical sentences expressing existence (see (5)) or locative meaning (see (6)):

(5) Carnivorous flowers exist.

(6) Some carnivorous flowers are there/in the moor.

In sum, if either the non-canonical structure condition or the semantic condition is not met, the sentence is not existential (in the sense of McNally 2008).

1.2. The *definiteness effect*

In certain linguistic environments **a class of nominal expressions is not tolerated**. Since definite DPs are among the unaccepted nominal phrases, the phenomenon was dubbed *the definiteness effect*. Existential *there*-constructions exhibit this restriction most strikingly:

(7) *There are some/two/at least four lizards (in the moor).*

(8) **There are the/every/both lizards (in the moor).*

Definiteness restriction (DE):
A construction exhibits the definiteness restriction if the DP (the pivot in the existential sentences) cannot be **a proper name or a pronoun**, or if the affected DP contains a common noun, it cannot be preceded by **definite or universal determiners** in neutral contexts (that is, in contexts where nothing else is implied than the mere stating of the semantic content of the sentence).

The puzzle that has already been **solved** in connection with the DE:

What are the relevant properties a DP must have in order to be admitted in the contexts showing the definiteness effect?

I assume that answers given **in the framework of the theory of generalized quantifiers** are correct (Barwise-Cooper 1981: only intersective determiners, Keenan 2003: only anticonservative determiners are allowed in existential sentences).

The puzzle that has **not** been **solved** yet:

WHY exactly those properties are the relevant properties the ones Barwise-Cooper (1981) or Keenan (2003) stipulated?

1.3. Formal semantic approaches to the definiteness effect: Barwise-Cooper (1981), Keenan (2003)

Framework: the theory of ***generalized quantifiers.***

Barwise and Cooper (1981): the property of the determiners which allows them to occur in existential sentences is ***intersectivity***:

(9) $DAB \Leftrightarrow D(A \cap B)(A \cap B)$

Example:

(10) *Some lizards are green* is true iff *some* ***green lizards*** *are* ***green lizards*** is true.

The intersectivity property determines a subcategorization on the category of determiners: definite and universal determiners are not intersective:

It is not the case that
(10') *Every lizard is green* is true iff *Every* ***green lizard is*** *a* ***green lizard*** is true.

Keenan (2003) argues that the relevant property is the **cons$_2$** (conservative on the second argument, also called **anticonservativity**) property:

(11) DAB $\Leftrightarrow$ D(A$\cap$B)B

Example:
(12) *Some lizards are green* is true iff *some* ***green lizards are green*** is true.

The deciding cases: *only/just/mostly* + bare nouns:
the intersectivity property fails, while the cons$_2$ property is OK:

(13) *Only lizards are green* is true iff
only ***green lizards*** *are* ***green lizards***. FALSE: intersectivity fails

(14) *Only lizards are green* is true iff
only ***green lizards are green***. TRUE: cons$_2$ works

Definite and universal determiners are not anticonservative:

(15) It is not the case that
<u>*Every lizard is green*</u> is true iff <u>*Every* ***green lizard*** *is green*</u> is true.
contingent tautology

Keenan (2003): ***all and only DPs with a cons$_2$ determiner*** (or some boolean compound of cons$_2$ determiners) ***are allowed*** in (productive) existential constructions.

1.4. Tell me WHY!

Why the $cons_2$ is the property of the allowed determiners in existential sentences? Does this follow from something?

My answer is **YES**; **$cons_2$ follows from**

- **a) a *universal* semantic property of determiners: CONSERVATIVITY ($cons_1$); and**
- **b) the *special* structural property of the *there*-sentences: they are *inverted* structures.**

Assumption: the *there* element signals that the structure of the sentence is non-canonical.
It follows then, that in order to recover the correct **semantic** structure of existential *there*-sentences **a semantic inversion** must take place.

The semantic inversion operation is **the very meaning of the *there*-element**: the *there* has a special lexical meaning operative on the meaning of the pivot's determiner.

The analysis is based on the **prototypical instances:** *there*-sentences containing an explicit locative PP:

(16) There are some green lizards in the garden.
Det N PP_{loc}

Assumption: the denotation of a locative PP can be considered as a set of points (Zwarts and Winter 2000)

The semantic structure of (16):

(17) $||\textit{there are}||^{M,g,w'}$ $||\text{Det}||^{M,g,w'}$ $||\text{N}||^{M,g,w'}$ $||\text{PP}_{loc}||^{M,g,w'}$ = ? D A B
where
D is the relation expressed by the determiner of the pivot DP
A is the denotation of the bare noun occurring in the pivot nominal
(a set of entities in w')
B is the denotation of the PP_{loc} (also a set of entities in w')
? stands for the interpretation of the *there (are)* part of (16).

The open question is the semantic role of the *there (are)* part of the sentence.

Starting point: the structure of existential sentences is non-canonical or inverted.
My ***basic assumption*** is that this can be grasped by attributing a special lexical meaning to the *there* element in these sentences:

The semantic interpretation of the *there (is/are/..)*-part of existential sentences is a special argument-changing function known as combinator C in combinatory logic (see e.g. in Hindley et al. 1972), given by lambda-terms in (18):

(18) $\mathbf{C} = \lambda f \lambda a \lambda b[f(b)(a)]$

Applying this combinator to the denotational structure given as D A B above, we get (19):

(19) $\lambda f \lambda a \lambda b[f(b)(a)]D\mathbf{AB} = \lambda a \lambda b[D(b)(a)]AB = \lambda b[D(b)(A)]B = D\mathbf{BA}$

The **interpretation** of *there (is/are/...)* – that is, **C -** is a function operating on another function (the determiner of the pivot DP) in a way that the original order of the arguments of D will be **reversed**. This means that the interpretation of (1) will be roughly equivalent with (20):

(20) *Some entities in the garden are lizards*.

This means that

There are some lizards in the garden is true exactly when

Some entities in the garden are lizards is true.

This is in accordance with the observation that the determiners occurring in existential sentences are usually symmetric (see Barwise and Cooper 1981).

Deriving the $cons_2$ property of the D in existential *there*-sentences:

Conservativity ($cons_1$) is a **universal** property of determiners:

(i) $DAB \Leftrightarrow DA(A \cap B)$ is valid, if D is conservative.

If the construction is existential, a "*there (be)*" part is present. Assuming that the semantic interpretation of the "*there (be)*" part is the combinator **C**:

(ii) $\mathbf{C}DAB = DBA$ (see (19))

Since **conservativity** is a universal property of determiners, it has to be met by the semantic structure of the sentence:

(iii) $DBA \Leftrightarrow DB(A \cap B)$

Re-inverting the structure in order to regain the original syntactic structure we get:

(iv) $DAB \Leftrightarrow D(A \cap B)B$. **This is exactly the $cons_2$ property**.

In sum, the **$cons_2$ property** of the determiners in existential *there*-sentences **is the result of** their **inverted structure**: anticonservativity follows from the universal conservative property of the determiners.

Keenan (2003) and Barwise-Cooper (1981) are both right:

Only is a non-conservative determiner (if it is a determiner at all):

(21) *Only lizards are green* is not equivalent truth-conditionally to
Only lizards are green lizards.

However, if the determiner in the pivot is conservative, then (i) + (iii) results in the intersectivity property of Barwise - Cooper (1981):

(v) $DAB \Leftrightarrow D(A \cap B)(A \cap B)$

This means that these determiners are symmetric:

(vi) $DAB \Leftrightarrow DBA$

This property seems quite reasonable if an argument-inverting operation is at work.

Conclusion:

The "definiteness effect" is not to be stipulated as a constraint because it becomes simply derivable: the DE-mystery disappears (at least in the case of existential sentences).

2. What combinators tell us about the logic of natural languages

2.1. General properties of combinatory logic:

1. Equivalent with λ-calculus but there are **no bound variables**.
2. All terms are interpreted as **functions**. Combinators are functions that can be characterized as transformations on terms.

One-step **reduction rules** for combinators with different arities, with their lambda-equivalents:

One-argument combinators:
Ix > x (identity) **I** = λx[x]

Two-argument combinators:
Kxy > x (constant function: cancellator) **K** = λxλy[x]
Txy > yx (permutator: type raising) **T** = λfλx[xf]
Wxy > xyy (duplicator): **W** = λxλy[xyy]

Three-argument combinators:
Bxyz > x(yz) (associator) **B**= λfλgλx[f(gx)]
Cxyz > xzy (permutator: argument-changing) **C**= λfλaλb[f(b)(a)]
Sxyz > xy(yz) (duplicator-associator) S= λfλgλx[fx(gx)]

Combinatory completeness (of the combinatory logic based on **K** and **S**):

If $M(X_1...X_n)$ is a term made up by application (using zero or more occurrences of each of $X_1...X_n$), we can find a combinator ***Z*** such that

$\boldsymbol{Z}X_1..X_n > M(X_1...X_n)$ (Bunder 2002, 232)

This means that all kinds of functions can be defined with combinators.

2.2.Returning to natural languages: why to use combinatory logic instead of lambda-calculus?

The lambda-formula given above as the equivalent of **C** combinator **has no special status** in the λ-calculus; you can define arbitrary functions in a similar fashion. However, **C** can play a distinguished role in combinatory logic.

Combinatory bases

Combinators can be defined by other combinators. The minimal combinatory base offered by Schönfinkel (1924) is {**K**, **S**}. However, this base contains the cancellator **K**.
If we want to eliminate argument-cancelling functions from the system, then the preferred sets of basic combinators contain the combinator **C** (Barendregt's combinatory basis consists of {**I**, **B**, **C**, **S**}, while Church preferred the {**I**, **B**, **C**, **W**} basis).
Thus **the theoretical status of the C combinator** is far more relevant in combinatory logic than that of the counterpart lambda-formula which is merely an *ad hoc* formalization.

Lambda-calculus and combinatory logic

There is no general translation algorithm from combinatory terms into lambda-terms:
different bases of combinators result in logics that are different in strength, and translation algorithms should be given separately for the different combinatory bases. (Bunder 2002)

Strengthening: if all of $X_1...X_n$ remain after the reduction, then the **Z** combinator is **relevant**: **Z** is over a combinatory base that does not contain a combinator with cancellative effect; that is, its base is {**B**, **C**, **I**, **W**} (or {**I**, **J**}). (Bimbó 2008)

Combinatory logic is connected to non-classical logics via typing.

2.3. Towards an implicational system: typed combinators

Combinatory terms are *functions*. Functions have a domain (a set of possible inputs) and a codomain (a set of possible outputs).
Functions with the same domain and codomain are of the same sort or type.

Definition of types

Basic types: the elements of a given set P (e.g. t and e in MG).
1. If $p \in P$, then p is a type (basic types are types)
2. if A, B are types then $(A \rightarrow B)$ is a type.

Type schemas for combinators:
I: $A \rightarrow A$ with categorial grammatical notation: A/A
K: $A \rightarrow (B \rightarrow A)$ with categorial grammatical notation: (A/B)/A
S: $(A \rightarrow (B \rightarrow C)) \rightarrow ((A \rightarrow B) \rightarrow (A \rightarrow C))$
with categorial grammatical notation: ((C/A)/(B/A))/((C/B)/A)
C: $(A \rightarrow (B \rightarrow C)) \rightarrow (B \rightarrow (A \rightarrow C))$
with categorial grammatical notation: ((C/A)/B)/((C/B)/A)
B: $(B \rightarrow A) \rightarrow ((C \rightarrow B) \rightarrow (C \rightarrow A))$
with categorial grammatical notation: ((A/C)/(B/C))/(A/B)

Type assignment:
1. Variables can be assigned arbitrary types
2. If $X: A \rightarrow B$ and $Y: A$, then $(XY): B$
3. If $Xx: A$, $x \notin X$, and $x:B$, then $X: B \rightarrow A$ (Bunder 234-235)

The type-assignment definition given in 2. and 3. gives the **Natural Deduction rules of implication** (2: → elimination, 3: → introduction) for intuitionistic logic (Bunder 235).

A type-assignment system is definable as a deduction system.

With the{**S, K**} base:

$\Delta \vdash \mathbf{S}$: $(A\rightarrow(B\rightarrow C)) \rightarrow ((A\rightarrow B) \rightarrow(A\rightarrow C))$
$\Delta \vdash \mathbf{K}$: $A\rightarrow(B\rightarrow A)$

$$\frac{\Delta \vdash M: A\rightarrow B \quad \Gamma \vdash N: A}{\Delta, \Gamma \vdash MN: B}$$ (Bimbó)

The {**S, K**} basis preferred by Schönfinkel results in **intuitionistic logic through type-assignment (with types as proofs).**
Strengthening (by eliminating the **K** combinator from the base because of its cancellative effect):
{**B**, **C**, **I**, **W**} results in a kind of substructural logic: **via the type-assignment theorems of relevance logic obtain.**

3. What can natural languages tell us about the combinatory base and, via their types, about the logic underlying them?

Categorial grammatical analyses of natural languages with the aid of combinators show the usefulness of **S** in natural languages (see Szabolcsi's and Steedman's works). However, the combinator **K**, being the constant function, has a cancellative effect, so it is to be avoided in compositional analyses. Thus, {**S, K**} basis does not seem strong enough for natural languages.

Mark Steedman: **combinator B** is essential **in treating unbounded dependencies** in natural languages; moreover, he argues in (Steedman 2002) that **it is behind some of our basic cognitive abilities**.
Szabolcsi Anna: the **meaning of reflexive pronouns** can be given by the **W combinator**.

Maleczki (1990): in order to treat the **syntactic variations in the argument-structures** of Hungarian, and in a more constrained way in English as well, **C combinator**'s presence should be assumed in the lexicon. The analysis of existential sentences given above with the **C** combinator as the lexical meaning of the *there (is/are)* gives us a key to the real understanding of **the definiteness effect**, whose long-standing puzzle status ceases in this way.

The **I** combinator is necessary because the composite combinator **CI** is the **type-raiser**, and that type raising is an inevitable process in natural languages had already been demonstrated before combinatory logic emerged as a tool in analysing natural languages.

Conclusion: the {**I, B, C, W**} combinators might give the base for the combinatory logic that underlies the compositional processes of natural languages.
Another advantage of using combinatory logic is that restrictions on the **allowed instantiations** of the types of combinators are supposedly not uniform across human languages. In this way, basic similarities and parametric variations in the different human languages could be discovered and demonstrated in a precise way.

An even more far-reaching consequence of the combinatory analysis is that **through type assignments** the {**I**, **B**, **C**, **W**} basis I argue for gives us the relevance logic $R_{\rightarrow}$: that is, the types of these combinators are equivalent the theorems of relevance logic $R_{\rightarrow}$. Thus our answer to the seemingly purely formal question what a combinatory base in the analysis of natural languages can be has far-reaching consequences: i**t results in a non-classical logic (relevance logic)**.

In sum, it seems that **from some** analyses arising from efforts to solve some **purely linguistic problems** we might arrive at a logical system. And if the analyses are independently motivated and supported by purely linguistic facts, **the logical system** we arrive at can certainly be regarded as a candidate for being "the" logic, or at least "one of the" logics underlying natural languages. If we accept that "logic is the science of knowledge", as Flach (2002) argues, then we can conclude that

purely formal methods applied to solve purely linguistic problems can lead us to an unbiased answer to the question what knowledge of a human language consists of.

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