Academia Grammaticorum Salensis Quinta Decima
Salos, Lithuania
July 29-August 4 2018

Counting and Measuring Crosslinguistically
Lecture 1: Numbers

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What we want: a syntactic and semantic analysis of number words. We restrict ourselves here to cardinals, e.g. one, two, three…..

PART I. What part of speech is a cardinal?

1. Syntactic distribution

A semantics for number words must account for the numerical expressions in at least the following type of constructions:

a. Prenominal modifier position

(1) a. *Two* cats were in the garden.
b. The *two* girls cooked a wonderful meal.
c. The guests were *two* girls.

b. Predicate positions:

(2) a. My reasons are *four*.
b. The children were *four*.

c. Argument position:

(3) a. *Two* plus *two* is *four*
b. *Two* is the only even prime number

d. 'determiners' of complex cardinals:

(4) *Two* hundred people stood in line.

The central questions:
(i) What is the type of the cardinal in its standard prenominal position as in (1a)?
(ii) What is the relation between the cardinal in prenominal position and its use as a singular term in (3)?
(iii) What is the relation between *two* and *hundred* in (4)?

We would like to extend our account to explain account the interpretation of numericals in constructions like (5) and (6) as well.

(5) *Two* kilos of strawberries went into this jam.
(6) *Hundreds* of people stood in line.

2. Bare numericals as singular terms
Prima facie evidence that numericals occur as singular terms:

(7) a. Two, four, six and eight are the first four even numbers.
b. Two is the only even prime number.
c. Two times two is four.
d. Two plus two is four.
e. Two and two make four.

Hofweber (2005), Ionin & Matushansky (2006): numericals are not singular terms. Hofweber (2005): *two* is a determiner at type <<**e**,**t**>,**t**>. All uses are derived from this. i.e.
Ionin & Matushansky (2006): *two* is a predicate modifier of type <<**e**,**t**>,<**e**,**t**>>.

(7e) is derived from (8) by NP ellipsis:

(7e) Two and two make four.
(8) Two ~~things~~ and two ~~things~~ make four ~~things~~.

What about (9), where the agreement is singular, and (7a-d):

(9) Two and/plus two makes four.

Hofweber: these are derived via ‘cognitive coercion’. This seems to be an extra-grammatical process of generalising from multiple specific instances to a general statement. Details are not given.

Whatever the type of *two* in *two (things),* there are the following pieces of evidence that apparent bare singulars like *two* are ambiguous between *two (things)* and *two* as genuine singular term.

(i) <u>the verb *count*:</u>
This is ambiguous between two meanings: ‘count how many N there are’ (10a) and ‘name in sequence a string of natural numbers (10b):

(10) a. I counted thirteen (*things, people, books*).
b. I counted (up) to thirteen (**things*).

Count (*how many*) (10a) takes a direct object either *two N* or *two* modifying an elliptical N. (This correlates with the observation in Rothstein (2010) that counting is always counting instantiations of a particular predicate.)
Count in the second sense must be followed by the P *to* and a numeral which must be bare.

Further, *count* in the first sense need not have a cardinal complement, while *count (up) to* must take a numerical complement.

(11) a. I counted the books
b. *I counted to the books.

This contrast appears in different languages:

(12) a. safarti šloš-esreh (devarim/anašim) (Hebrew)
I counted thirteen (things/books)
b. safarti ad šloš-esreh
I counted to thirteen

(13) a. J'*(**en**) ai compté treize. (French)
I **of-them** AUX-PAST counted thirteen.
"I counted thirteen (of them)."
b. J'(*en) ai compté jusqu'à treize.
I AUX-PAST counted until thirteen.
"I counted up to thirteen"

Compter in the sense of 'count how many' + bare numeral obligatorily appears with the clitic *en*, 'of them' (13a). *En* is impossible when *compter* is used in its second sense, (13b).

(ii). Statements about numbers using bare cardinals cannot be rephrased using the paradigm in (8). Numbers have second order properties which do not hold of *things*.

(14) a. *Two* is even / is a prime number.
b. #*Two things* are even / are a prime number.

(iii) Relations between numbers and relations between things are not the same relations: For example, numbers stand in the *bigger than/smaller than* relation. Pluralities of objects stand in the *more than/fewer than* relation. (15a) is equivalent to (15b), not to (15c).

(15) a. Two *is smaller than* three.
b. #Two things *are smaller than* three things.
c. Two things *are fewer than* three things.

(iv) Singular terms require singular agreement, while elliptical nouns modified by cardinals may take plural agreement.

(16) a. Four *is/*are* bigger than three.
b. Four (things) *are* more than three (things).
c. "I can't take you all in the car: Five are/is too many"

Conclusion: cardinals must have an interpretation as singular terms, as well as an interpretation in prenominal positions and as cardinal modifiers (with possibly null N heads).

3. **How are numericals interpreted prenominally?**

Whatever our account of numericals in prenominal position, we need our theory to explain the dual use in as a singular term and followed by a N.

(i) <u>Possibility 1: prenominal numericals are predicate modifiers</u> (Ionin & Matushansky 2006): There crucial claim is in two parts:
(a) *four* has the same interpretation in (17a) and (17b):
(b) *four* and *hundred* have the same interpretation in (b). They are both predicate modifiers at type <<**e**,**t**>,<**e**,**t**>>.

In (17a) *four* modifies *cats.*
In (17b) *hundred* modifies *cats* and *four* modifies *hundred cats*, as shown in (18):

(17) a. *four* cats
b. *four* hundred cats

(18) [four [hundred [cats]]]

A numerical *n* denotes a partition on a plural individual which has *n* parts:

(19) $\lambda P \lambda x_{pl}.\exists S\ [\ \text{PARTITION}(S, x) \wedge |\ S\ | = n \wedge \forall s \in S: P(s)]$ (I & M 2006: (5))

(17a) denotes a partition on the set of cats into four cells each containing a single cat (20b).
(17b) denotes a partition on a set of pluralities of cats into 4, with each individual cell itself portioned into 100 cells each containing an individual cat, giving the **multiplicative** effect (20c).

(20) a. *four*: $\lambda P \lambda x_{pl}.\exists S\ [\ \text{PARTITION}(S, x) \wedge |\ S\ | = 4 \wedge \forall s \in S: P(s)]$
b. *four cats*: $\lambda x_{pl}.\exists S\ [\ \text{PARTITION}(S, x) \wedge |\ S\ | = 4 \wedge \forall s \in S: \text{CAT}(s)]$
c. *four hundred cats:* $\lambda x_{pl}.\exists S\ [\ \text{PARTITION}(S, x) \wedge |\ S\ | = 4 \wedge \forall s \in S: \exists S'\ \text{PARTITION}(S', s) \wedge |\ S'\ | = 100 \wedge \forall s' \in S': \text{CAT}(s')]$

Four hundred and four cats is analysed as an NP conjunction as in (21):

(21) $[\text{four [hundred [}\sout{\text{cats}}\text{]]]}_{NP}$ and $[\text{four [cats]]}_{NP}$

This leaves three crucial facts unexplained.
(i) only a few lexically specified numerals occur as multiplicands: lexical powers like *hundred, thousand,* and *score* are acceptable, but numerals like *twenty* are not.

(22) a. four hundred/thousand/million cats
b. three score/dozen cats
c. *three twenty cats

(ii) the structure in (18) cannot explain why with lexical powers the multiplier is obligatory, while with other numbers it is impossible:

(23) a. **hundred* cats b. *one hundred* cats c. **one twenty* cats

(iii) All and only the lexical powers that occur in contexts such as (18) and need a preceding numerical (as in (23a)) can occur as approximative classifiers. This cannot be coincidental:

(24) a. *hundreds / thousands /scores* of cats
b. **twenties* of cats.

Together, this makes it look as if *hundred* and *four* should be of different types, so the major argument in favour of (18) and the predicate-modifier analysis does not hold. Furthermore, there is no natural relation between the predicate modifier type and the singular term.

b. <u>Possibility 2: prenominal cardinals are determiners</u>. (Barwise and Cooper (1981), Hofweber (2005).
Problems: (i)This does not give a natural account of (25):

(25) The number of planets is seven.

Hofweber (2005): in (25) *seven* is a focussed determiner. But he gives no details.

(ii) If prenominal numericals are determiners, then how does the DP lower to predicate type in *the guests are two boys*? See extensive discussion in Landman (2003).
Again, there is no natural relation between the predicate modifier type and the singular term.

NOTE: As we saw above, neither the determiner account not the prenominal modifier account allow us to explain bare singular uses of cardinals.

c. <u>Possibility 3: prenominal cardinals are predicates</u> (Landman 2003).
Landman (2003): Numericals are predicates, as in (26a.b). Cardinals are adjectives denoting sets of plural individuals with a specific cardinality. They modify nominals in predicate position (26c). Cardinals move to determiner position when there is no other determiner, inducing raising to generalized quantifier type via existential quantification (26d):

(26) a. $\lambda x.|\ x\ | = n$
b. *two:* $\lambda x.|\ x\ | = 2$
c. *two cats:* $\lambda x.CATS(x) \wedge |\ x\ | = 2$
d. *two cats:* $\lambda P.\exists x[CATS(x) \wedge |\ x\ | = 2 \wedge P(x)]$

This naturally explains how numerals appear as bare predicates (27a), as ‘determiners’ of predicate phrases (27b), after the determiner *the* (27c) and post-adjectivally (27d) (examples after Landman 2003):

(27) a. My reasons are two.
b. The inhabitants of the barn are two cats.
c. The two cats live in the barn.
d. The hungry two cats ate the old food. The well-fed two cats ignored it.

Landman shows that it is supported *at least/exactly* contrasts: In predicate position numericals have an "exactly two" reading:

(28) a. #The inhabitants of the barn are two cats, maybe even three.
b. Two cats, maybe even three, live in the barn,

The predicate in (26c) denotes a set of plural cats with exactly two atomic cat-parts, giving the 'exactly' reading) .

(29) Ronya and Emma are two cats: $\lambda x.\text{CATS}(x) \wedge |\ x\ | = 2\ (r \sqcup e)$
$= \quad \text{CATS}(r \sqcup e) \wedge |\ r \sqcup e\ | = 2$

The argument in (26d) is derived from the predicate in (26c) via existential quantification.

(30) Two cats are in the barn: $\exists x[\text{CATS}(x) \wedge |\ x\ | = 2 \wedge \text{IN THE BARN}(x)]$

The assertion that a plural entity consisting of exactly two cats is in the barn is consistent with there being a plural entity consisting of more than two cats in the barn, thus the 'at least' reading is allowed.

Note that the 'exactly' reading comes back in (27c): *the two cats* means *the exactly two cats:* the definite article requires a unique plural entity of two cats as its denotation, and that is only possible if there are exactly two cats in the domain.

We conclude that we can treat cardinals as predicates/adjectives which may raise to determiner position.

We now need to relate the predicate adjective use of the cardinal to the use of the number as a singular term.

PART II: A Fregean analysis of number words.

4. A property theory analysis of numbers.

We adopt (and adapt) Chierchia’s (1985) property theory, which follows Frege (1884).
Property theory associates with predicates:
- an applicative interpretation at type <e,t>
- a corresponding property-correlate at the type of individuals, π.

Two operations $^\cap$ and $^\cup$ switch between them.

For the applicative interpretation $\lambda x.\text{WISE}(x)$, $^\cap\text{WISE}$ is the individual property correlate (=WISDOM), $^{\cup\cap}\lambda x.\text{WISE}(x) = \lambda x.\text{WISE}(x)$

(31) a. $[\![\text{wise}_{<e,t>}]\!] = \lambda x.\text{WISE}(x)$
b. $[\![\text{wise}_{\pi}]\!] = {}^\cap\lambda x.\text{WISE}(x)$

For cardinal numerals, we start out with a standard modifier interpretation at type <e,t>, as in (32a) , with the cardinality function defined as in (32b) and *x* ranging over plural individuals. Predicate uses are indicated in (33). Determiner uses are induced via type shifting.

(32) a. $[\![\text{four}_{<e,t>}]\!] = \lambda x.|x| = 4$
b. $|x| = n \leftrightarrow |\{y: y \sqsubseteq_{\text{ATOMIC}} x\}| = n$

(33) a. $[\![\text{four guests}]\!] = \lambda x.\text{GUESTS}(x) \wedge |x| = 4$
b. $[\![\text{the guests are four}]\!] \quad \lambda x.|x| = 4\ (\sigma\{x: \text{GUESTS}(x)\})$
$= |\sigma\{x: \text{GUESTS}(x)\}| = 4$

four as a singular term is an expression of type n and denotes the individual property correlate of the set in (32a), i.e. (34)

(34) $^\cap(\lambda x.|x| = 4)$.

The central equation which defining numbers is (35):

(35) $n = {}^\cap(\lambda x.|x| = n)$ (for numbers in the domain of type n)

Second order properties at type <n,t> e.g. *is a prime number* apply only to numerals at type n.

Lexical powers, unlike the simple numerals illustrated in (36) are of type <n,<e,t>> and combine with a singular term denoting a number n to yield a cardinal predicate:

(36) a. $[\![\text{hundred}_{<n,<e,t>>}]\!] = \lambda n \lambda x.|x| = 100 \times n$
b. $[\![\text{two hundred}_{<e,t>>}]\!] = \lambda x.|x| = 100 \times 2$
c. $[\![\text{two hundred}_{n}]\!] = 200 = {}^\cap(\lambda x.|x| = 200)$.

(37) $[\![\text{two hundred cats}]\!] = \lambda x.\text{CATS}(x) \wedge |x| = 100 \times 2$
Once this analysis is given, various ways of deriving complex numerals are available.

For instance we derive *two hundred and four* at type n from (36a), shifting the cardinality predicate meanings in (34) and (36c) to the property correlate type:

(38) a. $[\![\text{and}_{<n,<n,n>>}]\!]$ = $\lambda m\lambda n.\ n+m$
b. $[\![\text{two hundred and four}_{n}]\!]$ = $\lambda m\lambda n.\ m+n\ (200)$
= $\lambda n.\ 200+n \quad (4)$
= 204
c. $[\![\text{two hundred and four}_{<e,t>}]\!]$ = $^{\cup}204 = \lambda x.\,|\,x\,| = 204$

'+' can be defined in terms of the sum relation: n + m takes disjoint plural objects with cardinalities n and m respectively, sums them and gives back the number correlate of equivalence class of the cardinality of their sum. × can be given a similar interpretation.

This explains the three issues presented in (22) – (23):

(i) only a few lexically specified numerals occur as multiplicands since only numericals of type <n, <e, t>> combine with 'prenumeral determiners':

(22) a. four hundred/thousand/million cats
b. three score/dozen cats
c. *three twenty cats

(ii) with lexical powers the multiplier is obligatory because it is of type <n <e,t>>. If a numerical is of type <n,<e, t>> not only can it combine with a 'prenumeral determiner', it must combine with one.

(23) a. **hundred* cats b. *one hundred* cats c. **one twenty* cats

(iii) All and only lexical powers, i.e. numbers at type <n,<e,t>> occur as approximatives, with the syntax of classifiers: they must be followed by *of* and a bare plural, as in (38):

(24) a. *hundreds / thousands /scores* of cats
b. **twenties* of cats.

They can occur with definite determiners preferably if the nominal is modified by a relative clause:

(39) a. the hundreds of cats (#that I saw in the garden)
b. the ten kilos of flour (#that should have been delivered this morning)
c. The hundreds of rabbits (that you promised me I should see) never appeared.

Since only lexical powers can be used as classifiers in this way , approximative readings must exploit the type <n,<e,t>>. I suggest the appropriate semantic operation is (40a), which applies to *hundred* in (40b):

(40) a. $\text{APPROX}_{<\mathbf{n},<\mathbf{e},\mathbf{t}>> \rightarrow <\mathbf{e},\mathbf{t}>}$: $\lambda n\lambda x.|\ x\ | = n \times m \rightarrow \lambda x.\exists n[n \geq 2 \wedge |\ x\ | \geq n \times m]$
b. $\text{APPROX}([\![\text{hundred}_{<n,<e,t>}]\!])$ = $\text{APPROX}\ (\lambda n\lambda x.|\ x\ | = n \times 100)$
= $\lambda x.\ \exists n[n \geq 2\ \wedge |\ x\ | \geq n \times 1000]$

The APPROX operation does three things:
- it existentially quantifies over the n argument,
- it changes the '=' to '$\geq$' and
- it adds the clause '$n \geq 2$'. (Note the plural morphology associated with the operation.)

It gives the set of individuals with a cardinality greater than $100 \times n$, where n is greater than or equal to 2, i.e.with a cardinality greater than 200. It combines with a predicate via modification:

(41) $\lambda P \lambda x. \exists n[n \geq 2 \wedge |x| \geq n \times 100 \wedge P(x)]$ $(\lambda x.CATS(x))$
$= \lambda x. \exists n[n \geq 2 \wedge |x| \geq n \times 1000 \wedge CATS(x)]$

Approximators can stack as in *tens of thousands of cats* via via function composition as in (42): Since APPROX applies to the whole expression, every lexical power is marked plural.

(42) a. *thousand* $\circ$ *hundred* = $\lambda n \lambda x. |x| = n \times 1000 \circ \lambda n \lambda x. |x| = n \times 100$:
$= \lambda n \lambda x. |x| = (^{\cap}\lambda y. |y| = n \times 100) \times 1000$
b. APPROX($\lambda n \lambda x. |x| = (^{\cap}\lambda y. |y| = n \times 100) \times 1000$) =
$\lambda x. \exists n [n \geq 2 \wedge |x| = (^{\cap}\lambda y. |y| = n \times 10) \times 1000]$
c. *hundreds of thousands of cats*:
$\lambda x. \exists n [n \geq 2 \wedge |x| = (^{\cap}\lambda y. |y| = n \times 10) \times 1000 \wedge CATS(x)]$

This analysis is Fregean in two senses:

1. Cardinals are predicates with saturated and unsaturated expressions. The unsaturated expression denotes a cardinality property. The saturated expression denotes a number. This is a direct instantiation of Frege's (1892) insight that properties had 'two modes of presentation'. In the unsaturated mode, it applies to an argument to form a sentence, and in the saturated mode, it can itself be the subject of a predication.

2. Frege argued that the number *n* as an object denotes the equivalence class of sets with cardinality *n*. This is captured directly. Frege treats *four* as denoting the equivalence class $\{X: |X| = 4\}$ i.e. 4 is a property of sets. e defined the cardinality predicate as denoting a property of plural individuals. i.e. *four* denotes the set of plural individuals with four atomic parts. A plural individual with cardinality 4 is the sum of a set with 4 atomic parts, so one definition can be reduced to the other, for example by the **CARD** function. **CARD** maps sets of sets with cardinality n onto sets of plural individuals with cardinality *n*, the meaning of the cardinal predicate.
For $Y = \{X: |X| = n\}$: **CARD**$(Y) = \{x: \exists X \in Y: x = \sqcup X\} = \{x: |x| = n\}$

PART III: Numbers classifiers and measures

5. Where else do numbers appear at type n?

Numbers appear at type n in
(i) statements about numbers: *Two plus two equal four/ Two is a prime number.*
(ii) as parts of complex numbers: ***two** hundred;* ***two** hundred and **four***
Do they occur anywhere else at type n?

Yes; they occur at type n in measure expressions;

(43) *two kilos* of flour, *three litres* of water, *two hundred and ninety three* Euros
(5) *Two* kilos of strawberries went into this jam.

In *two kilos*, *kilo* combines with *two* to form a complex predicate giving the property that a quantity has if it has the value 'two kilos' on the weight dimension. (Gawron 2002, Landman 2004, Krifka 1989, Chierchia 1998, Rothstein 2009, 2011, forthcoming, Partee and Borschev 2012).

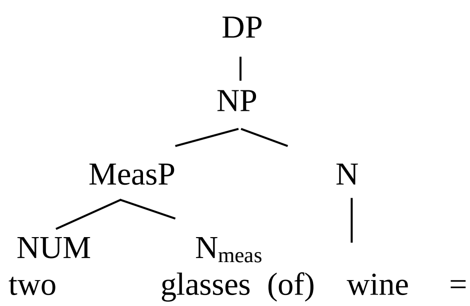
The measure head *kilo* is an expression of type <n, <e,t>>. It applies to a number to give a complex predicate.

(44) kilo: $\lambda n\lambda x.\mathrm{MEAS}_{weight}(x) = \langle n, \mathrm{KILO}\rangle$
two kilos: $\lambda x.\ \mathrm{MEAS}_{weight}(x) = \langle 2, \mathrm{KILO}\rangle$
two kilos of flour: $\lambda x.\mathrm{FLOUR}(x) \wedge \mathrm{MEAS}_{weight}(x) = \langle 2, \mathrm{KILO}\rangle$

The same structure is used for measure readings of nominal classifiers like *glass* work the same way: *glasses* is a modifier, which combines with the numeral *two* to form a modifier which modifies *wine* (20):

(45) two glasses of wine:

(46)



$\lambda x.\ \mathrm{WINE}(x) \wedge \mathrm{MEAS}(x) = \langle 2, \mathrm{GLASS}\rangle$

(Evidence in support of these structures - Rothstein 2009, 2016, 2017)

Evidence in support of parallel interpretations for measure heads and lexical powers:

Note that in Russian approximative inversion constructions, lexical powers are treated as measure heads:

(47) a. desjat' knig
ten books
'ten books'

b. knig desjat'
books ten
'about ten books'

(48) a. dvesti gramm muki
two hundred grams flour
'two hundred grams of flour'

b. gramm dvesti muki
grams two hundred flour
'about two hundred grams of flour'

c pjat' litrov moloka
five liters milk
'five litres of milk'

d. litrov pjat' moloka
litres five milk
'about five liters of milk'

(49) a. sorok tysjač mašin
forty thousands cars
'forty thousand cars'

b. tysjač sorok mašin
thousands forty cars
'some forty thousand cars'

c. *mašin sorok tysjač
cars forty thousand.

<u>6 Some Conclusion:</u>

The data supports:

(i) treating numbers as properties within a property theory framework. This means they have both a referential function at type n and a predicative function at type <e,t>.

(ii) analysing multiplicative heads or lexical powers such as *hundred* as expressions at type <n, <e,t>>

(iii) treating lexical powers as structurally analogous to measure heads such as *kilo* and *litre.*

Note further:

- When numericals are predicates modifiers as in *three cats* they always modify an N. This expresses the fact that we always count entities under a certain description. Three couples is more people than three people.
- There are restrictions on what predicates denote countable categories:

(50) a. How many cups and saucers are there on the table?
#seven. ✓three cups and two saucers
b. How many cups and saucers do we need?
c. How many boys and girls are there in the class? ✓15.
d. How many cats and dogs do you have? #seven. ✓three cats and four dogs.
e. How many cats and dogs is the vet looking after? 25

Note, there are many other kinds of numericals, for example:
1. ordinals: *first, second, third*
2. fractions: *a third, a half, two fifths*
3. cardinals: + fractions: *two and half*
4. decimals: *two point five*

Presumably the semantics of these is derived from the meaning of cardinals!

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