Making sense of the spatial metaphor for number in natural language

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Abstract — It is cross-linguistically very common to use locative prepositions as modifiers of numerals. For example, the Romanian example in (1), taken from Corver and Zwarts (2006), uses the locative *sub 20* ("below 20") to indicate that there were fewer than 20 children at the party, just like English would use *under* in a similar construction.

(1) Au fost sub 20 de copii la petrecere.
Have been below 20 de-prep children at party
'There were under 20 children at the party'

What allows such combinations of spatial prepositions and numerals to be meaningful phrases? In this short note, I will propose that scale *structure* may be an essential part of the answer to this question.

1 Introduction

It is cross-linguistically very common to use locative prepositions as modifiers of numerals. As noted by Corver and Zwarts (2006), combinations of prepositions and numerals typically involve prepositions that are compatible with the vertical axis. For instance, English uses *under* n and *over* n to be synonymous to *fewer than* n and *more than* n, respectively.

(2) John found over / under 50 typos in the manuscript.

Many other languages, across language families, show a similar restriction on combinations of spatial prepositions and numerals. For example, (3) - (6) illustrate the use of vertical prepositions in Hebrew.

(3) ha-kelev šel yoni yašen mi-taxat la-šulxan
the-dog poss. Jon sleeps from-under to.the-table
'Jon's dog sleeps/is sleeping under the table.'

(4) yoni matsa mi-taxat le-me'a šgi'ot ba-sefer
Jon found from-under to-100 mistakes in.the-book

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'Jon found under/below 100 mistakes in the book'

(5) ha-tmuna tluya me-'al la-ax
the-picture hung from-top to.the-fireplace
'The picture hangs/is hanging above the fireplace'

(6) yoni matsa me-'al le-me'a šgi'ot ba-sefer
yoni found from-top to-100 mistakes in.the-book
'Jon found over/above 100 mistakes in the book'

Similarly in Greek:[1]

(7) To skili tu Yani kimate kato apo to trapezi.
the dog the.GEN John.GEN sleeps under from the table
'John's dog is sleeping under the table.'

(8) De tha epireastun i sindaxis pu ine kato apo hilia evro
not will affected the pensions which are under from 1000 euro
'The pensions that are under 1000 euro will not be affected"

While many languages use vertical prepositions to combine with numerals to express quantity, so far no language has been found that uses a horizontal prepositions to express *fewer* or *more*.[2] Corver and Zwarts attribute the verticality involved in the modification of numerals to Lakoff and Johnson's metaphor *more is up;less is down*, as witnessed in examples like *the number is high*, *my income rose*, etc. (Lakoff and Johnson, 1980). According to this metaphor, we conceptualise quantity as a pile of stuff - more stuff means a pile that is taller, less stuff means a pile that is not as vertically pronounced.

On a descriptive level, the metaphor makes a lot of sense. The metaphor does not make clear, however, how it manages to intrude into the compositional semantics as to allow the combination of the spatial meaning of preposition and the essentially non-spatial meaning of a numeral. Nor does it explain why we do not find alternative metaphors that involve different axes. In this paper, I will propose that the roots of the descriptive metaphor are to be found in the *scalar semantics* of numerals. In a nutshell, I will claim that the vertical metaphor works because only the vertical spatial axis has properties that are compatible with properties of numeral semantics.

2 Space and number

What allows a preposition like *under* to meaningfully combine with a numeral like *100*? From the viewpoint of compositional semantics, such combinations are unexpected on the assumption

[1] Blok (2015) reports on a sample of 15 languages in which she found dynamic prepositions that were compatible with vertical motion and that did double service as a numeral modifier. This could be taken as further support for the vertical spatial metaphor for number, in the sense that it is not restricted to locative aspects of space, but extends to directional ones. (See Nouwen 2008, 2010; Blok 2015 for arguments that directional aspects of spatial expressions are active when applied to the domain of numerals. For instance, there are important interpretative differences between *under 100* and *up to 100*.) However, directional prepositions tend to be compatible with multiple axes at once. English *up to* may be used both vertically (*In 1996, the water rose up to the level indicated here*) and horizontally (*Please walk up to the line and have an agent scan your ticket*). An anonymous reviewer adds to this complication, the observation that *up* may be used to convey contents that are void of a clear axial spatial meaning, as in *dig up* or *break up*. Taking all this into consideration, it is hard to use directional preposition to make claims about the spatial orientation of metaphors applied to numbers. In the remainder of this note, I will therefore avoid such prepositions.

[2] A seeming exception may be *north* and *south*, as in *He earns north/south of $100.000 a year.* It seems to me however, that such examples could be explained since in a two dimensional representation of wind directions, north points up and south points down. I know of no language that allows *east/west of $100.000*.

that *under* is an essentially spatial expression and *100* is essentially non-spatial. It could of course be that this latter assumption is unwarranted. In other words, it could be that combinations like *under 100* are to be fully expected once we revise our understanding of the content of number words.

For this reason I have to start by asking: What is a number? Or, more precisely: What is the semantic content of a number word?[3] The current consensus in psychology is that number *concepts* are to be defined by the biologically determined number sense innately possessed by humans as well as by other animals (Dehaene, 2011). Linguistic semantics on the other hand adopts an essentially Platonic stance. Numerals are often thought to denote abstract objects called degrees or higher order objects (properties, quantifiers, modifiers, etc.) derived from such an abstract cardinal notion (see, for instance, Rothstein, 2013, 2016, and references therein; the relevant discussion goes back to Frege 1892). The two opposing views, the rich conception of number in psychology versus the unadorned one in linguistics, may look miles apart at first sight, but they are by no means irreconcilable.

Compositional semanticists often reduce the content of words to only those aspects that are grammatically active. Take a noun like *bird*. Our conceptual knowledge tells us that a blackbird is a more prototypical bird than an ostrich. However, the semantic content of *bird*, *blackbird*, and *ostrich* need not encode this information, since there are no grammatical constructions that tap into this conceptual knowledge, not even constructions that specialise in indicating relative category membership, like the comparative or degree modifiers. For instance, while we can say of John that he is *very tall*, it makes no sense to say of a blackbird that she is *very (much) a bird* while the ostrich is *not very much a bird*. Hence, from the viewpoint of semantics, the content of the word *bird* is stripped from the prototypicality effects found in cognitive psychology, not because they are thought not to exist, but simply because they are (thought to be) inaccessible to the grammar.[4]

Similar considerations have dominated the semantic view on numerals. Grammar supplies morphology to compare the magnitude of quantities (and qualities) as evidenced by English *more* and *many/much*. If this were the only kind of operation on numbers that languages display, then it suffices for the goals of linguistic semantics to assume that the content of number words are abstract entitities that are related to each other via an ordering (see below). Such a simplistic conception of number is much too simplistic for our number sense more generally, but by adopting the simpler concepts the linguistic model of meaning can be very specific about which aspects are and which aspects are not accessible to linguistically encoded operations.

Now what about the combinations of spatial expressions and numerals, like *under 100*, that are the focus of this note? May these be an indication that the number concept adopted by linguistics is too simplistic? It is very tempting to think that they indeed are, for there is ample evidence in cognitive (neuro)psychology of the existence of a mental *number line*, a spatial representation of numerical values used for the cognitive operations that make up our number sense. The most compelling evidence comes from the so-called SNARC: the spatial numerical association of response codes (Dehaene et al., 1993).[5] The SNARC manifests itself in reaction time differences

[3] I am indebted to an anonymous reviewer for urging me to take this particular route.

[4] In fact, there are some arguments in the literature that suggest that prototype structure *is* sometimes accessible, for instance for cases like *John is a real idiot*, as in Morzycki 2011; see also Sassoon 2007. Note that such claims do not affect my general point: not all psychologically attested aspects to concepts are part of the semantic content of the corresponding word, given that the aspects in question could be inaccessible to the grammer.

[5] A different kind of example dates back to the nineteenth century, to Francis Galton's discovery of so-called *number forms* (Galton, 1880, 1881). Number forms are fixed spatial structures that some people associate to the numerical series. Galton interviewed friends at the Royal Society to see if whenever they thought of numbers these were accompanied by some sort of visualisation. Several of them reported very specific number forms. One of the participants in his study, identified as T.M., notes: "The representation I carry in my mind of the numerical series

as a result of spatial biases in numerical tasks. In a typical experiment that demonstrates the SNARC effect, participants are asked to perform a simple numerical task. For instance, they need to decide whether a number between 1 and 9 presented to them on (the middle of) a screen is odd or even. There are two response buttons, one for each hand. For half the partipants odd is left and even is right and for the other half it is the other way around. The SNARC effect is the effect that the response times depend on the hand used. Typical French participants were slower to decide 8 is even if the even button was in their right hand than if it was in their left hand. The interpretation of this effect is that the numbers between 1 and 9 are somehow mentally represented as going from left to right. In other words, low numbers are associated with the left periphery, while high numbers show a bias to the right.

The effect is (among other things) linked to writing direction. If you are used to read from left to right, then numbers will typically be represented as increasing from left to right. Indeed, as Dehaene et al. show, Iranian subjects used to writing from right to left, show the opposite effect. Ito and Hatta (2004) demonstrate a vertical SNARC effect with Japanese participants.

More generally, the number sense is often argued to be biologically determined (Dehaene, 2011, see McCrink and Opfer 2014 and reference therein for discussion). To cognitive neuropsychologists this suggests that numbers are the relatively rich, inherently spatial, concepts that allow the brain to do the things it does with them. This may be a cue to semanticists to alter their simplistic conception of number. That is, if we are seeking for an explanation of why spatial prepositions may compose with numerals to form meaningful phrases, the solution may indeed lie in adopting the richer concepts of number that include spatial orientation.

There is one essential reasons why I think this will not work.[6] If the content of number words is directly linked to the mental number line, then we are left with no hope to account for the exclusively vertical orientation of spatial modifiers of number words. Given that the number line is horizontal for most human, why is *left of 100* infelicitous in any language? If we do take the content of numbers to contain spatial features, then these clearly do not match the features of the available spatial modifiers.

This leaves me to conclude that the spatial aspects of number found in *language* are separate from spatial aspects of number found in the non-linguistic number sense. In what follows, I will therefore adopt the simplistic linguistic semantic conception of numbers. This means that I will need to seek the source of space-number combinations in languages not just in properties of numbers, but also in properties of space.

3 The scalar semantics of numerals

A semantic scale is an ordering of values that is associated with the meaning of a certain expression (see Solt, 2015, for a comprehensive overview). For instance, if we are comparing two students and say of them that one of them is *smart* but the other one is *very smart* then a very common way to make semantic sense of this is to assume that adjectives like *smart* map individuals to

is quite distinct to me, so much so that I cannot think of any number but I at once see it (as it were) in its peculiar place in the diagram."

Contemporary studies of number forms identify the phenomenon as a form of synesthesia, with an occurrence of roughly 12% (for instance, Ward et al., 2009; Tang et al., 2008). The shape of number forms varies greatly across synesthetes. In other words, although they are indicative of the potential spatial grounding of number cognition, they clearly do not display any systematic connection between numerical and spatial features.

[6] Another issue may be what happens with the spatial content of numerals when it is not clearly accessed as in phrases like *more than 100*? In other words, how do you shut the spatial content off when it is not needed? From the psychological perspective, however, one might think there is no issue here, since *all* numerical operations, included that encoded by *more*, are in some sense spatial (given that numbers are inherently spatial).

measures of smartness. In this case, the smart measure of the first student is inferior to the measure of the second.
Scalar semantics, then, always involves two ingredients, a measure and what is said of the measure. For (9), at stake is how smart John is, and the sentence expresses that John's measure of smartness is relatively high.

(9) John is very smart.

Technically, a scale is an ordered set of measures of a certain kind, that is a pair $\langle D, > \rangle$, where D is the set of abstract objects that represent the relevant measures, the set of *degrees*, and $>$ is the ordering defined on them (for instance, Kennedy, 2007).[7]
Scales are most prominently associated with gradable adjectives, since these typically concern properties that hold of entities to a certain degree. However, it is clear that the verbal and the nominal domain host scalar semantics too (for instance, Neeleman et al., 2004). One clear example of scalar semantics outside the adjectival domain is the semantics of quantity. Numerals and quantifiers like *many* and *few* address a measure of amount and thus require a semantic scale of quantity.
One needs to assume that quantifiers and numerals are somehow supplied with a relevant measure of quantity, for instance through a silent measure function (Hackl, 2000; Landman, 2004).[8] For instance, a sentence like (10) is true if and only if the measure in (11) is *many / four*.

(10) John found many / four typos in the manuscript.

(11) the number of typos that John found in the manuscript

We can simply think of the scale of quantity as the rational numbers paired with their standard ordering, which I will write as $>_q$. This allows a neat parallel between adjectival scalarity and the scalarity involved in quantity. For instance, it in principle allows for a uniform treatment of *more* in (12) and (13).

(12) John is more beautiful than Mary.

(13) John ate more biscuits than Mary.

In this setup, a quantifier like *many* can be thought to express the property of being a quantity that is $>_q t$ where t is some relevant contextual threshold. More straightforwardly, numerals now correspond to points on the scale.
All this is a very roundabout way of saying that, semantically, numerals correspond to numbers. However, the scalar machinery guarantees that these numbers are not just isolated points, but by their very scalar nature connected to other numbers via the ordering $>_q$. It is exactly this connection to a scale that I propose is crucial in understanding the spatial metaphor for numerals. On the one hand, scales of the kind I have been discussing here[9] are obviously not inherently

[7] It is standard to assume that scales are slightly more specific than this in that they also specify a dimension of measurement. For the purpose of this note, we can ignore this component.

[8] Alternatively, one could assume the measure is part of the meaning of the noun (Cresswell, 1976) or of the quantifier itself (Barwise and Cooper, 1981). Such choices are immaterial for our purposes.

[9] At this point it may be good to point out that numerals are also scalar in a different way. The notion of scale above concerns abstract objects that live in the semantic realm. A different kind of scale is an ordered set of *words*, one that may be targetted by functional expressions such as *only*, *even*, *at least* and *at most*. For instance, the relevant scale in (14) is [assistant professor < associate professor < full professor] and *only* indicates that John is relatively low on that scale, in the sense that he is not a full professor. In (15), the scale is [winning the bronze medal < winning the silver medal < winning the gold medal] and *at most* expresses that the speaker does not think it is possible that Ussain will win gold.

spatial. They are completely abstract objects. Yet, I will claim that the link to space is to be found in the structural properties of these scales. In a nutshell, I will propose that the quantity scale in natural language semantics has properties that only coincide with properties of the vertical spatial axis; it is structurally different from the lateral (left-right) and the frontal (front-back) axis.

4 Connecting properties of scales to properties of spatial axes

As I explained in the previous section, *scalarity* is an essential component in the semantics of quantity. Scales are ordered sets of measurements. Such orderings can differ in a number of important respects. Measurement theory (Stevens, 1946) distinguishes three kinds, or *levels*, of scales.[10] The simplest one is the ordinal scale. This is an ordering of elements that traces only their relative positions. There is for instance no notion of distance between the elements. Ordinal numbers are the most natural examples of an ordinal scale. By telling you who came 1st, 2nd and 3rd in a race, I am only conveying order. We cannot extract any information about distances between the participants in the race.

Interval scales carry more information: they are ordered sets of elements that trace distance. An example is clock time. The ordering tells us that 9pm comes after 8pm and 11am is before 2pm. However, on top of that it includes a notion of distance. The "amount" of time between 1pm and 2pm is exactly the same as the "amount" between 2pm and 3pm.

The most involved notion of a scale are *ratio orders*. Like *interval scales*, ratio scales trace the distance between ordered elements. In addition, however, they allow for multiplication. An example is the weight scale. Obviously, the difference between 2kg and 3kg is 1kg and the difference between 4kg and 5kg is also 1kg. But we also know that 4kg is twice as heavy as 2kg. In contrast, this is unavailable for clock time: it would be odd to say that midnight is twice as late as noon. Or that 7am is twice as late as half past three at night. This is not to say that time is never measured on a ratio scale. Duration, for instance, is ratio. If you waited 7 hours for your connecting flight, then you waited twice as long as the person who waited 3 and a half hours.

What is at stake for the difference between interval and ratio scales is the availability of a non-arbitrary 0. On a clock there are only arbitrary starting points. We could say that a day starts at midnight, but that point on the scale does not play any significant role on the scale. The same goes for the 0 on a thermometer. In celcius, we assign the freezing point of water to 0, but this is of course arbitrary. We can measure temperature in many different ways; for instance, using Fahrenheit, the 0 will be somewhere completely different. In other words, there is no natural 0 for temperature.[11]

There is a natural 0 for length, for instance. Here too, we could measure using different conven-

(14) John is only an associate professor.

(15) Ussain will at most win silver.

The numerical series form a scale in this sense, too: *only thirty-six* expresses that this number is rather low and *at most thirty-six* excludes the possibility of more (Geurts and Nouwen, 2007; Nouwen, 2010; Coppock and Brochhagen, 2013, amongst many others).

[10] Stevens distinguishes a fourth level of measurement, the *nominal* level. However, this is a kind of measurement where there is no ordering at all.

[11] Note that this is so despite of the fact that from a scientific point of view, the temperature scale comes with an abolute zero value. This kind of scientific knowledge does not impact our folk understanding of temperature, or at least not that part of our understanding that informs how we *talk* about temperature. Someone who is unaware of the scientific facts about temperatures is not suddenly going to change the way they talk about temperature, once they learn there is nothing below $-273.15\ ^{o}$C. In other words, what matters is not our scientific understanding, but our non-scientific conceptualisation.

tions. What is 2.5 centimeters in the metric system is just under 1 inch using the imperial unit. However, 0 centimeter is the same length as 0 inch: the 0 for length is clearly not arbitrary. So, length in contrast to temperature is a ratio scale.
Quantity scales are clearly ratio orderings too. We do not have systems of counting quantities that start at a dozen or at a pair: 0 designates the absence of stuff; in this sense, it is an unmovable non-arbitrary starting point.
Now here comes the crucial observation. Take an arbitrary point in the everyday space we inhabit. Only the vertical axis will give us a fixed second position to compare this point with, namely the ground underneath it. If we divide the space up in a lateral (left-right) axis, a frontal (front-back) axis and a vertical axis, then arguably only the latter has this kind of non-arbitrary 0. Engrained in our notion of space is a notion of *ground*.[12] The vertical dimension of space starts just below our feet. In the horizontal dimension there is no comparable point. We could take our *self* as a reference point, but this does not correspond to a fixed spatial position; it moves when we move.
In this sense, a vertical spatial axis, but not a horizontal one, has the crucial property needed to constitute a ratio scale. This brings me to the following proposal:

(16) **The scalar metaphor condition:** expressions that function on a scale S can only be metaphorically used on a scale S' if S is at least as high a level of measurement as S', where the relevant hierarchy of levels is: ordinal $<$ interval $<$ ratio.

For spatial metaphors, this condition boils down to the requirement that horizontal metaphors can only be used for interval or ordinal scales. The vertical axis, with its dedicated 0 element, can be used for every kind of scale. As such, vertical scalar metaphors are expected to dominate in natural language. Yet, in specific cases, horizontal metaphors should be available. In the next section I will put this proposal to the test.

5 The scalar metaphor condition at work

One conceivable option is that a language adopts the scalar metaphor condition by generalising to the worst case. Since there will always be ratio scales in language (quantity, for instance), vertical spatial metaphors will be adopted for these as well as for other, lower-level scales. While this definitely remains an option, it is more interesting to note that there clearly are languages that match scale and metaphor more finely.
As I mentioned above, clock time constitutes an interval scale. This makes it, in principle, compatible with horizontal spatial metaphors. Indeed, this is exactly what Haspelmath (1997) found: "The cross-linguistic evidence overwhelmingly confirms the view that time is conceptualized in terms of space, more particularly in terms of the frontal axis. A large number of languages from a wide variety of families show this association either synchronically or diachronically." (p. 56, see also Hill, 1978, page 524).
For instance, in Dutch, the preposition *voor* has both a frontal spatial use and a use for clock time:

(17) Jan stond voor zijn huis.
Jan stood *voor* his house.
'Jan stood in front of his house'

[12] An anonymous reviewer wonders whether *gravity* may play an essential role in the special nature of the vertical axis. This is very likely, especially given the fact that gravity provides an absolute notion of direction to the vertical axis. As the reviewer notes, what is *behind* and *front*, or *left* and *right* is dependent on the object in question and/or the perspective taken. Gravity determines in a way that is completely independent from anything what is *up*.

(18) Jan valt normaalgesproken voor 11 uur in slaap.
Jan falls normally *voor* 11 hour in sleep.
'Normally, Jan falls asleep before 11 o'clock.'

The vertical preposition *onder* (under) is unavailable in such a sentence. That is, there is no way to make sense of a sentence like (20), which I indicate using a hash tag.

(19) Jan's hond slaapt onder de tafel.
Jan's dog sleeps under the table.

(20) #Jan valt normaalgesproken onder middernacht in slaap.
Jan falls normally *onder* midnight in sleep.

As soon as we move from clock time to *duration time*, and hence from an interval scale to a ratio scale, the vertical metaphor is available again and the horizontal one is not:

(21) Deze printer is opgewarmd in #voor / onder de 24 seconden.
This printer is warmed-up in *voor* / *onder* the 24 seconds.
'This printer warms up in fewer than 24 seconds'

Other examples of horizontal metaphors include cases of ordinal scales. In Dutch, *voor* can express pure relative order, as in (22), which discusses the outcome of a public vote on the best pop song of all time.

(22) Imagine van John Lennon eindigde op nummer 1 voor Bohemian Rapsody van
Imagine of John Lennon ended on number 1 *voor* Bohemian Rapsody of
Queen.
Queen.
'John Lennon's imagine ended up on number 1; number 2 was Queen's Bohemian Rapsody'

What I have not found, however, is any evidence that the temperature scale is ever addressed using a horizontal metaphor. Given the scalar metaphor condition and the case of, for instance, Dutch *voor* for clock time, one would expect to find such prepositions in combination with temperatures too. However, in Dutch, and many other languages I checked, temperatures are strongly associated with the vertical scale, despite their interval nature.

(23) Bij een lichaamstemperatuur #voor / onder de 35 graden krijg je het moeilijk.
By a body temperature *voor* / *onder* the 35 degrees get you it difficult.
'You'll have a hard time once your body temperature drops below 35 degrees.'

There are several possible explanations of this. It may be tempting to think that one of these explanation is the fact that from a purely scientific point of view, temperature *is* a ratio scale, given the existence of an absolute zero. However, this fact is in no way part of our folk understanding of temperature and is therefore unlikely to play a part in language. (See footnote 11). Having said that, it is actually not uncommon to treat the temperature scale as if it were a ratio scale, typically with 0 degrees celcius as the non-arbitrary 0 point. For instance:

(24) Temperatures in the south will be almost twice as warm as the seasonal average, but it will be cold and wet in the north.[13]

(25) Phew!.. Twice as warm as Corfu! [...] [W]hile the Greek holiday spot could only man-

[13]The Independent, 20/2/2016

age a paltry 8C (46F), Britons basked in the sun as temperatures reached 16C (60F) yesterday.[14]

(26) Scotland and northern parts of the England will not be quite as warm as southern areas, but most places are likely to be hotter than the average March temperature of 9C, with some twice as warm as average. [15]

I would like to emphasise that the absense of horizontal metaphors for temperature are still in line with the scalar metaphor condition I outlined above. While I have not given an explanation of why horizontal metaphors are more rare than perhaps expected, the condition does explain the abundance of vertical metaphors, simply because a vertical axis is due to its structure more metaphorically applicable than a horizonal one.

6 Conclusion

In summary, I am proposing that the source of vertical metaphors for expressing information about amounts is to be found in the scalar properties shared by the vertical axis and the quantity scale. The scalar metaphor condition predicts that the vertical axis is more generally applicable as a basis for a metaphorical mechanism than either of the horizontal axes are, since only the vertical axis comes with a non-arbitrary zero and is thus structurally similar to the highest level of measurement, that of a ratio ordering.
The condition also predicts that horizontal metaphors should at times exist with lower-level measurement scales, and this is confirmed by the not uncommon use of frontal axis prepositions to address clock time. It is not clear however why horizontal metaphors do not have a wider distribution, for instance to address temperature. As I suggested above, this may have to do with our naive understanding of some scales, imposing ratio properties to an interval scale. It could also simply point to the worst case strategy reasoning I alluded to above: the default spatial metaphor is vertical, since it is fully general in its compatibility.

References

Barwise, J. and R. Cooper (1981). Generalized quantifiers and natural language. *Linguistics and Philosophy 4*(2), 159–219.

Blok, D. (2015). The semantics and pragmatics of directoinal numeral modifiers. In *Proceedings of SALT 25*. Cornell.

Coppock, E. and T. Brochhagen (2013). Raising and resolving issues with scalar modifiers. *Semantics & Pragmatics 6*(3), 1–57.

Corver, N. and J. Zwarts (2006). Prepositional numerals. *Lingua 116*(6), 811–836.

Cresswell, M. (1976). The semantics of degree. In B. Partee (Ed.), *Montague Grammar*, pp. 261–292. Academic Press.

Dehaene, S. (2011). *The number sense: How the mind creates mathematics*. OUP USA.

Dehaene, S., S. Bossini, and P. Giraux (1993). The mental representation of parity and number magnitude. *Journal of Experimental Psychology: General 122*(3).

[14] The Mirror, 12/3/2007
[15] The Telegraph, 7/6/2016

Frege, G. (1892). über begriff und gegenstand. *Vierteljahrsschrift für Wissenschaftliche Philosophie 16*, 192–205.

Galton, F. (1880). Visualised numbers. *Nature 21*.

Galton, F. (1881). Visualised numbers. *Psychology 10*.

Geurts, B. and R. Nouwen (2007). At least et al.: the semantics of scalar modifiers. *Language 83*(3), 533–559.

Hackl, M. (2000). *Comparative Quantifiers*. Ph. D. thesis, Department of Linguistics and Philosophy, Massachusetts Institute of Technology.

Haspelmath, M. (1997). *Indefinite Pronouns*. Oxford: Clarendon Press.

Hill, C. A. (1978). Linguistic representation of spatial and temporal orientation. *Berkeley Linguistics Society 4*, 524–538.

Ito, Y. and T. Hatta (2004). Spatial structure of quantitative representation of numbers: Evidence from the snarc effect. *Memory & Cognition 32*(4), 662–673.

Kennedy, C. (2007). Vagueness and grammar: The semantics of relative and absolute gradable predicates. *Linguistics and Philosophy 30*(1), 1–45.

Lakoff, G. and M. Johnson (1980). *Metaphors We Live By*. University of Chicago Press.

Landman, F. (2004). *Indefinites and the type of sets*. Blackwell Publishers.

McCrink, K. and J. E. Opfer (2014). Development of spatial-numerical associations. *Current directions in psychological science 23*(6), 439–445.

Morzycki, M. (2011). The several faces of adnominal degree modification. In *Proceedings of the 29th West Coast Conference on Formal Linguistics (WCCFL)*, Somerville, Mass. Cascadilla Press.

Neeleman, A., H. v. d. Koot, and J. Doetjes (2004). Degree expressions. *The Linguistic Review 21*(1), 1–66.

Nouwen, R. (2008). Directional numeral quantifiers. SALT 18.

Nouwen, R. (2010). Two kinds of modified numerals. *Semantics and Pragmatics 3*(3), 1–41.

Rothstein, S. (2013). A fregean semantics for number words. In M. Aloni, M. Franke, and F. Roelofsen (Eds.), *Proceedings of the 19th Amsterdam Colloquium*.

Rothstein, S. (2016). *The Semantics of Counting*. Cambridge University Press.

Sassoon, G. (2007). *Vagueness, Typicality and Gradability, A comprehensive semantic analysis*. Ph. D. thesis, Tel Aviv University.

Solt, S. (2015). Measurement scales in natural language. *Language and Linguistics Compass 9*(1), 14–32.

Stevens, S. S. (1946). On the theory of scales of measurement. *Science 103*, 677–680.

Tang, J., J. Ward, and B. Butterworth (2008). Number forms in the brain. *Journal of Cognitive Neuroscience 20*(9), 1547–1556.

Ward, J., N. Sagiv, and B. Butterworth (2009). The impact of visuo-spatial number forms on simple arithmetic. *Cortex 45*(10), 1261–1265.