Subatomic quantification

Marcin Wągiel

OJ591 Topics in linguistics

Introduction

Ontological intuition dating back to Pre-Socratics

cf. Varzi (2016)

- entities are often made up of smaller entities (parts) related to each other in a particular manner

Cognitive fact

Elkind et al. (1964), Kimchi (1993), Boisvert et al. (1999)

- humans conceive entities as being made up of smaller entities related to each other in a particular manner

Figure 1: Part-whole perception (Elkind et al. 1964)

Introduction

Vital question

- to what extent is this fact relevant for natural language semantics?

Claims

- natural language semantics is sensitive to subatomic part-whole structures
- subatomic quantification (quantification over parts) is subject to identical restrictions as quantification over wholes
- some quantificational operations including counting presuppose particular topological relations

Outline

- Standard assumptions in lattice-theoretic approaches
- The three claims
  1) Topological relations in natural language
  2) General counting principles
  3) Subatomic quantification
- Evidence
  - cross-linguistic behavior of partitives
  - Italian irregular plurals
  - Polish *half* words
  - multipliers such as English *double*
- Analysis

Lattice-theoretic approaches to pluralities

Standard assumptions

- standard mereology

  Link (1983) and many others
- only $\sqsubseteq$ and $\sqcup \Rightarrow$ entities equivalent to sums of their parts
  - opposing views
    - mereotopology (Grimm 2012)
    - probabilistic Type Theory with Records (Sutton & Filip 2017)
- sorted domains $\Rightarrow \sqsubseteq_m \times \sqsubseteq_i$, $\sqsubseteq_e \times \sqsubseteq_p$

  e.g., Link (1983), Bach (1986)
  - opposing views
    - situated part structure (Moltmann 1997, 1998)
    - Iceberg semantics (Landman 2016)

Lattice-theoretic approaches to pluralities

- no relationship between $\sqsubseteq$ and intuitive part-of relations
  - "it should be this way"

    e.g., Pianesi (2002), Champollion (2010)
  - opposing views
    - situated part structure (Moltmann 1997, 1998)
    - Iceberg semantics (Landman 2016)
- atomicity: atoms $\Rightarrow$ objects without proper parts
  - opposing views
    - natural units (Krifka 1989)
    - Iceberg semantics (Landman 2016)

Lattice-theoretic approaches to pluralities

Mereology

- study of parthood $\Rightarrow$ parts and wholes
  Leśniewski (1916), Leonard & Goodman (1940); Link (1983)
- set theory: set membership $\in$ vs. subset relation $\subseteq$ $\Rightarrow$ $\{a\} \neq a$
- mereology $\Rightarrow$ no sets as abstract objects
- one primitive parthood relation $\sqsubseteq$

(1) Reflexivity
$\forall x[x \sqsubseteq x]$

(2) Transitivity
$\forall x \forall y \forall z[(x \sqsubseteq y \wedge y \sqsubseteq z) \rightarrow x \sqsubseteq z]$

(3) Antisymmetry
$\forall x \forall y[(x \sqsubseteq y \wedge y \sqsubseteq x) \rightarrow x = y]$

Lattice-theoretic approaches to pluralities

Semi-lattice

- partial order
- parthood $\sqsubseteq$ and sum formation $\sqcup$

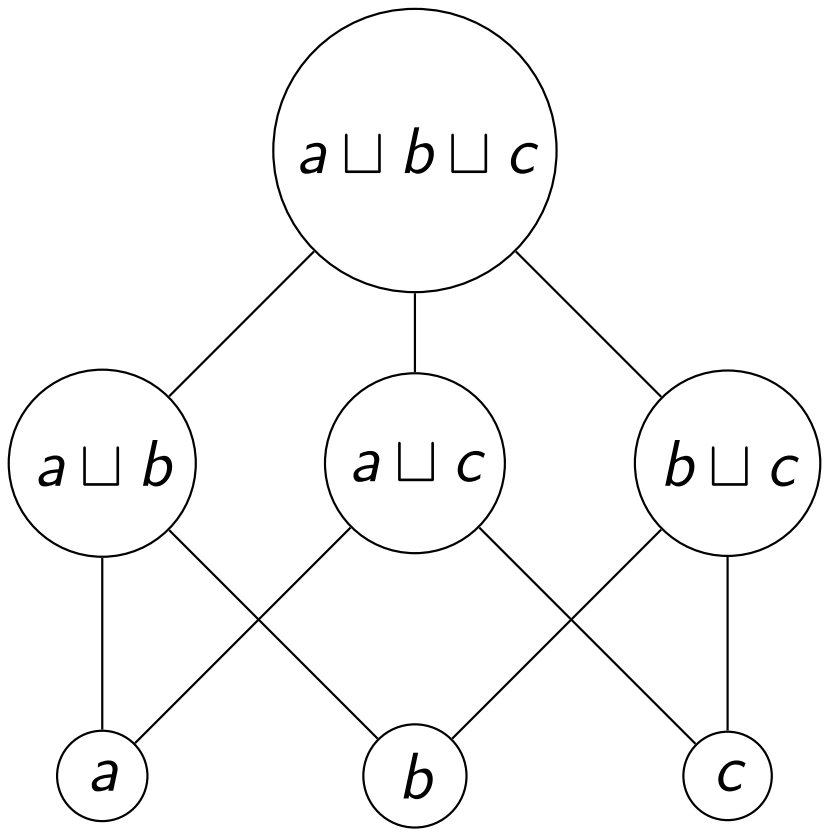


Figure 2: Semi-lattice

Lattice-theoretic approaches to pluralities

Atomicity

- proper parthood $\sqsubset \Rightarrow$ not reflexive
- atom $\sqsubset$ mereological concept
- atom $\Rightarrow$ entity which has no proper parts
- atomic vs. atomless mereologies

(4) Proper part

$x \sqsubset y \stackrel{\text{def}}{=} x \sqsubseteq y \wedge \neg(y \sqsubseteq x)$

(5) Atom

$\forall x[\textsc{atom}(x) \leftrightarrow \neg\exists y[y \sqsubset x]]$

(6) Atomicity

$\forall x \exists y[y \sqsubseteq x \wedge \neg\exists z[z \sqsubset y]]$

Mereotopological structures in natural language

Mereotopology

- mereotopology
  Kuratowski (1922), Casati & Varzi (1999), Grimm (2012)
  - mereology augmented with topological relations
  - no atomicity understood as having no proper parts
  - individual $\Rightarrow$ a maximally strongly self-connected sum of overlapping entities making up a whole
- semantics of number
  - singular individuals $\Rightarrow$ mereotopology, topological relations between parts
  - plural individuals $\Rightarrow$ mereology, no topological commitments
- further applications possible

Mereotopological structures in natural language

- NL expressions sensitive to topological notions
  - count nouns, aggregates, collective number
    Grimm (2012)
  - swarm nouns
    Henderson (2017)
  - Slavic derived aggregate nouns
    Grimm & Dočekal (to appear)
  - verbs of separation such as *dismember*, *dismantle*
  - expressions involving quantification over parts
  - *part* words
    Wągiel (2018)
  - multipliers
    Wągiel (to appear)

Mereotopology

Mereology + topological notions

Casati & Varzi (1999), Grimm (2012)

- connectedness $\mathrm{C} \Rightarrow$ primitive relation
- implied by overlap

(7) Reflexivity
$\forall x[\mathrm{C}(x, x)]$

(8) Symmetry
$\forall x \forall y[\mathrm{C}(x, y) \leftrightarrow \mathrm{C}(y, x)]$

(9) Parthood $\rightarrow$ connectedness
$\forall x \forall y[x \sqsubseteq y \rightarrow \forall z[\mathrm{C}(x, z) \rightarrow \mathrm{C}(z, y)]]$

Mereotopology

Mereology + topological notions

Casati & Varzi (1999), Grimm (2012)

- connectedness $\mathrm{C} \Rightarrow$ not transitive
- a and $b \Rightarrow$ connected
- b and $c \Rightarrow$ connected
- a and $c \Rightarrow$ not connected

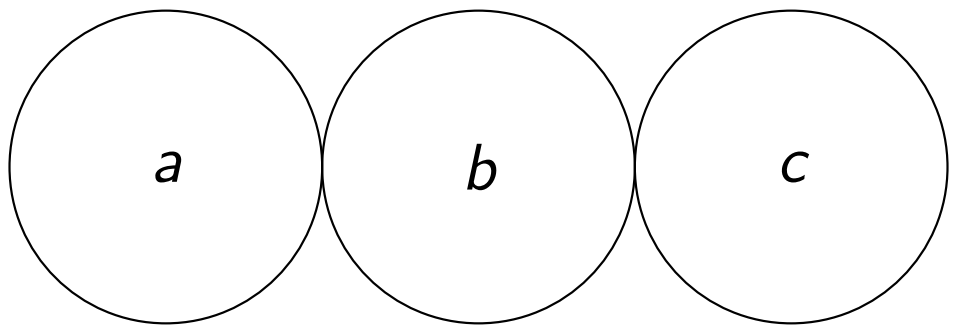


Figure 3: Connectedness and transitivity

Mereotopology

Mereology + topological notions

Casati & Varzi (1999), Grimm (2012)

- internal part $\Rightarrow$ entity included in a whole
- internal overlap $\Rightarrow$ part of an entity included
- tangential overlap $\Rightarrow$ 'touching' entities

(10) Internal part

$$\mathrm{IP}(x, y) \stackrel{\mathrm{def}}{=} x \sqsubseteq y \wedge \forall z[\mathrm{C}(z, x) \rightarrow \mathrm{O}(z, y)]$$

(11) Internal overlap

$$\mathrm{IO}(x, y) \stackrel{\mathrm{def}}{=} \exists z[\mathrm{IP}(z, x) \wedge \mathrm{IP}(z, y)]$$

(12) Tangential overlap

$$\mathrm{TO}(x, y) \stackrel{\mathrm{def}}{=} \mathrm{O}(x, y) \wedge \neg \mathrm{IO}(x, y)$$

Mereotopology

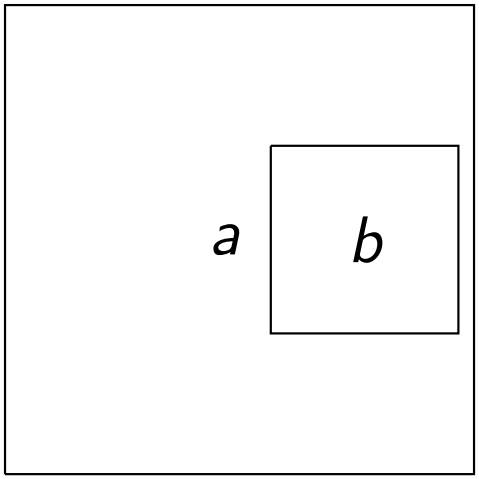


Figure 4: Internal part

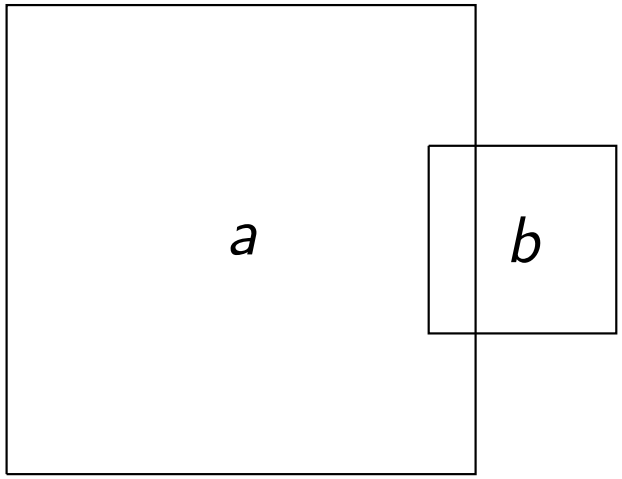


Figure 5: Internal overlap

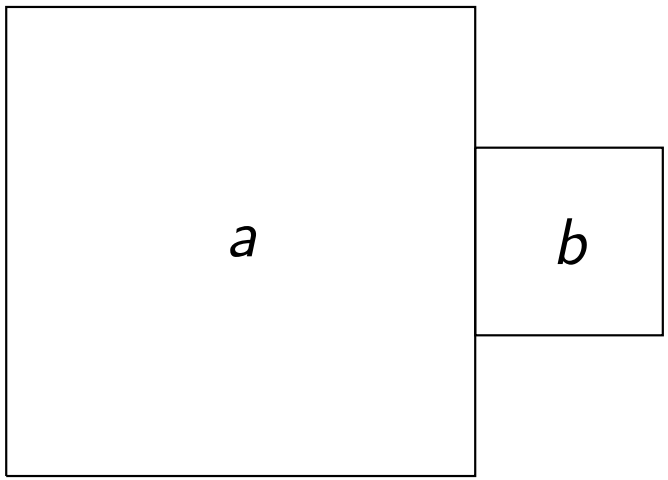


Figure 6: Tangential overlap

Mereotopology

Mereology + topological notions

Casati & Varzi (1999), Grimm (2012)

- interior, exterior, closure, boundary

(13) Interior

$ix \stackrel{\text{def}}{=} \oplus X$ where $X = \{y : \text{IP}(y, x) = \textsc{True}\}$

(14) Exterior

$ex \stackrel{\text{def}}{=} i(-x)$

(15) Closure

$cx \stackrel{\text{def}}{=} -(ex)$

(16) Boundary

$bx \stackrel{\text{def}}{=} -(ix \oplus ex)$

Mereotopology

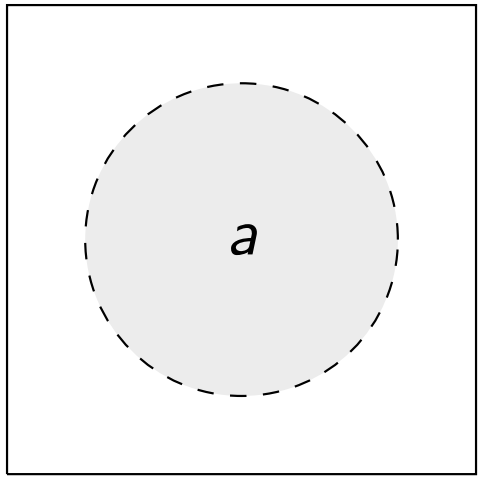


Figure 7: Interior

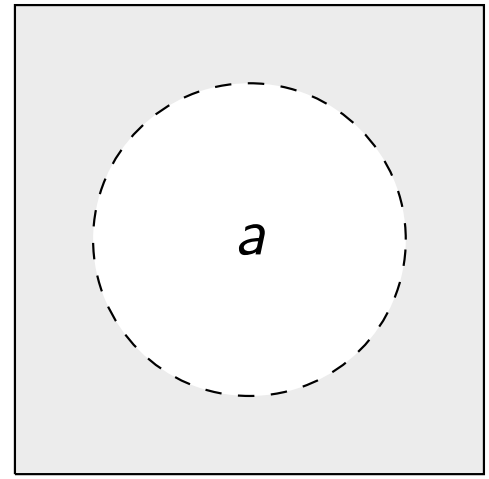


Figure 8: Exterior

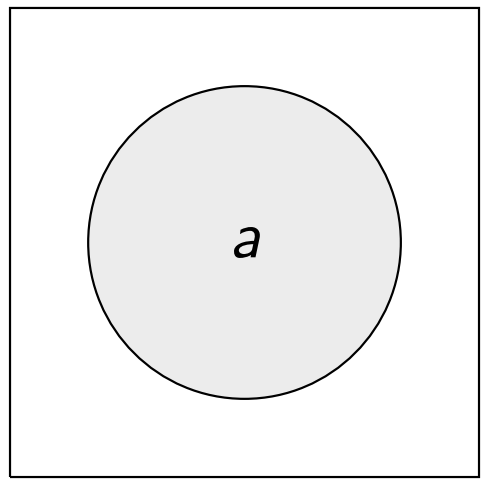


Figure 9: Closure

Mereotopology

Self-connected entity

(17) $\mathrm{SC}(x) \stackrel{\mathrm{def}}{=} \forall yz[\forall w(\mathrm{O}(w,x) \leftrightarrow (\mathrm{O}(w,y) \vee \mathrm{O}(w,z))) \rightarrow \mathrm{C}(y,z)]$

- any two parts that form the whole are connected to each other

Strongly self-connected entity

(18) $\mathrm{SSC}(x) \stackrel{\mathrm{def}}{=} \mathrm{SC}(x) \wedge \mathrm{SC}(ix)$

- entity's interior is self-connected $\Rightarrow$ excludes touching objects

Mereotopology

Maximally strongly self-connected relative to a property

(19) $\text{MSSC}(P)(x) \stackrel{\text{def}}{=}$
$P(x) \wedge \text{SSC}(x) \wedge \forall y[P(y) \wedge \text{SSC}(y) \wedge \text{O}(y, x) \leftrightarrow y \sqsubseteq x]$

Strongly self-connected

- every part of the entity is connected to (overlaps) the whole

Maximality

- anything else which has that property, is strongly self-connected, and overlaps is part of it

Mereotopology

Capturing objects

- integrated wholes $\Rightarrow$ parthood and connectedness
- arbitrary sums $\Rightarrow$ only parthood

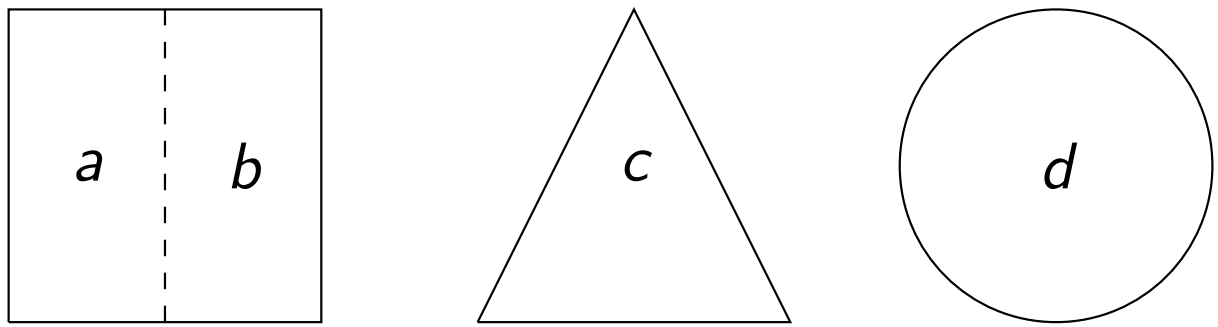


Figure 10: Wholes vs. sums

Mereotopology

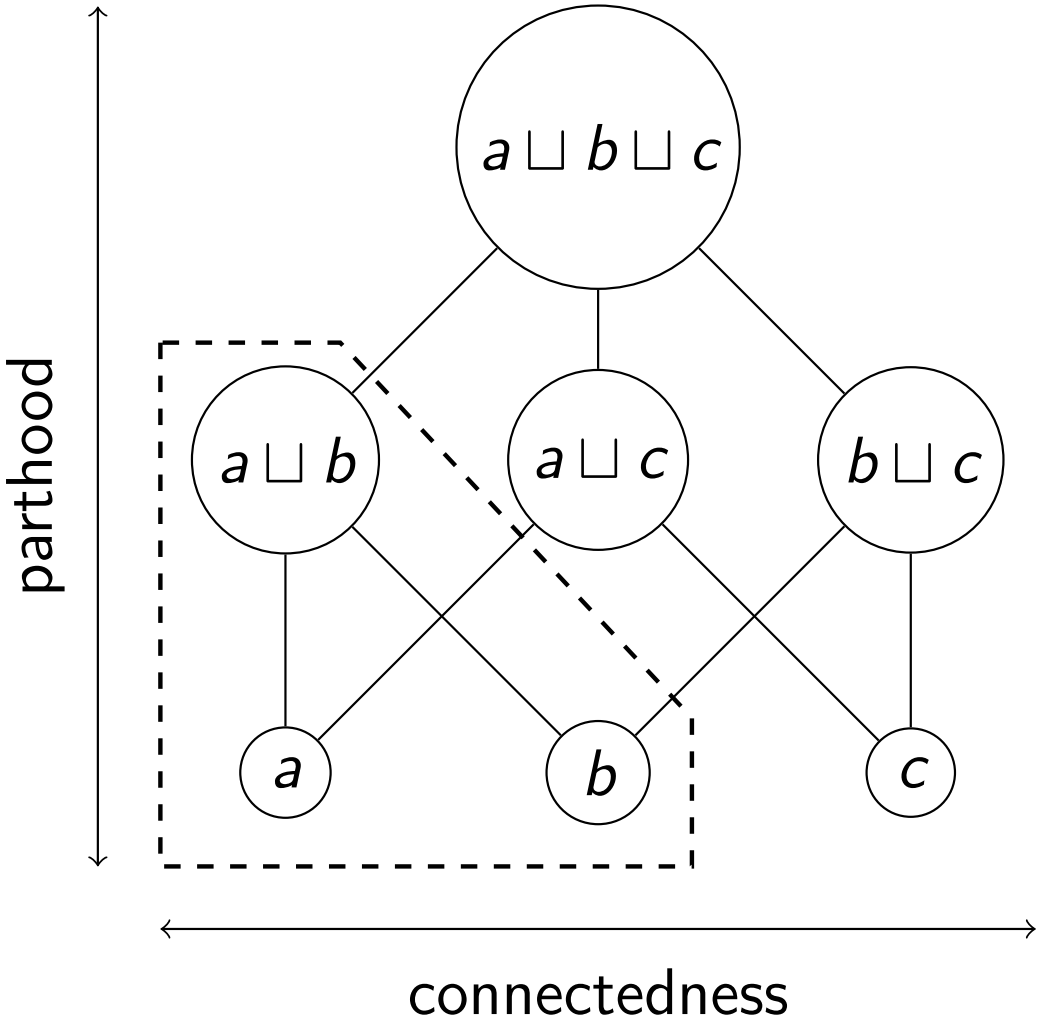


Figure 11: Parthood and connectedness (based on Grimm 2012, p. 136)

General counting principles

- mapping entities to numbers ⇒ 1-to-1 correspondence
  - non-overlap ⇒ disjoint entities (Landman 2011, 2016)
  - maximality ⇒ mereological exhaustivity
  - integrity ⇒ individuated and integrated whole

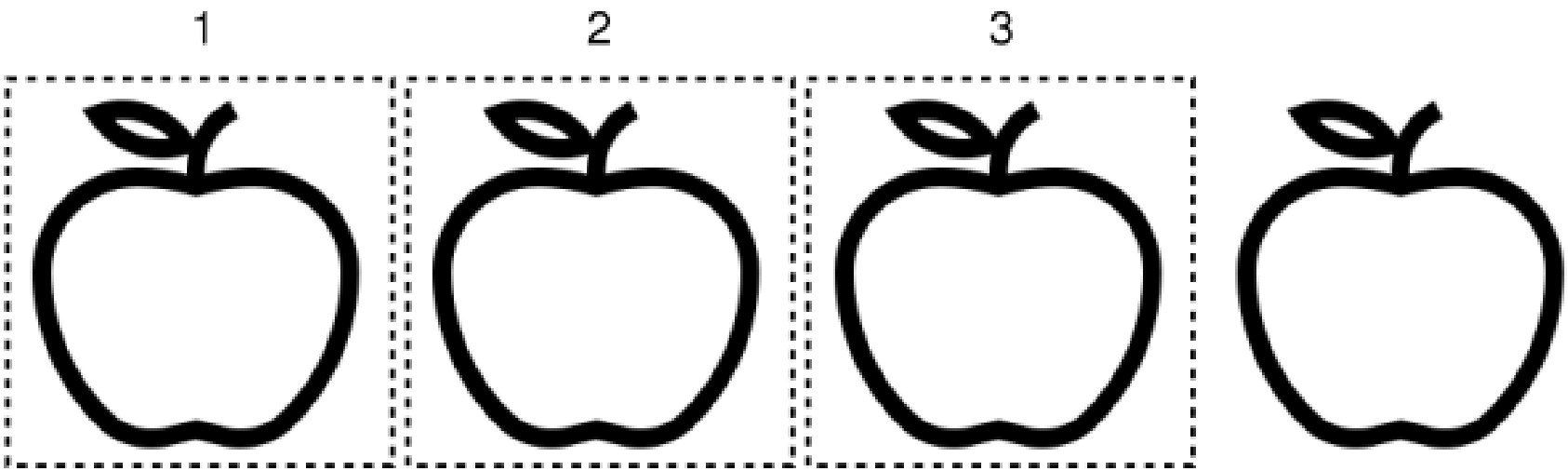


Figure 12: Counting

General counting principles

- illegal counting
  - assigning a number to less than a whole entity
  - summing up complementary parts
  - overlapping entities

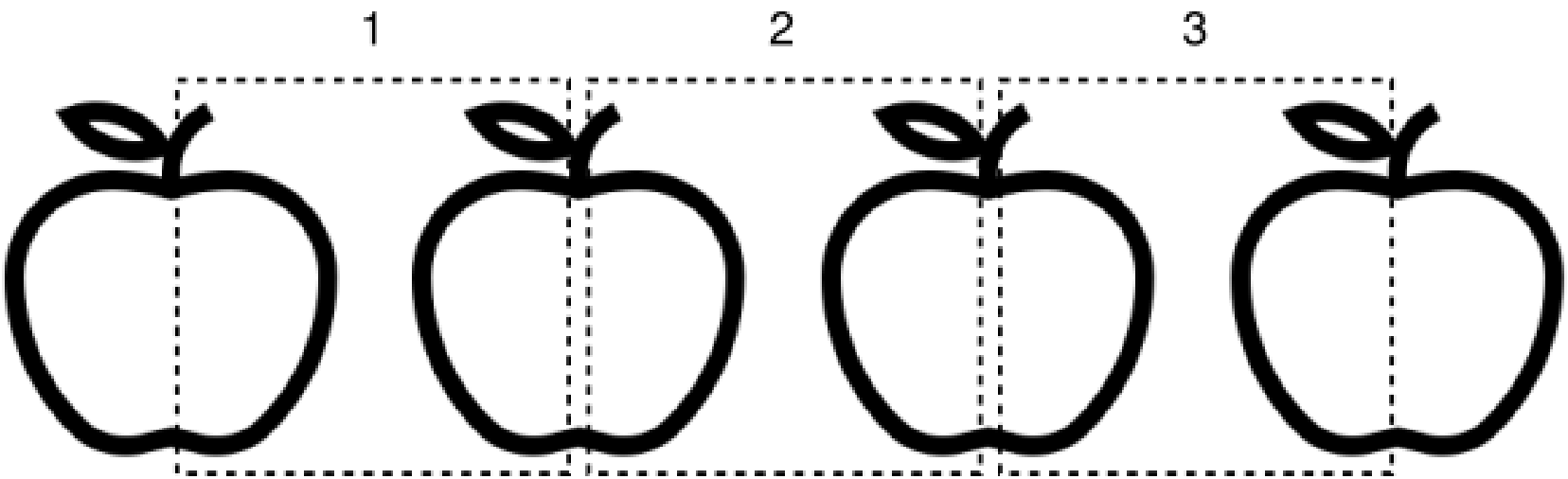


Figure 13: Illegal counting

General counting principles

- independent evidence

  Shipley & Shepperson (1990), Dehaene (1997)
  - children between 3 and 4 years
  - count only discrete integrated objects

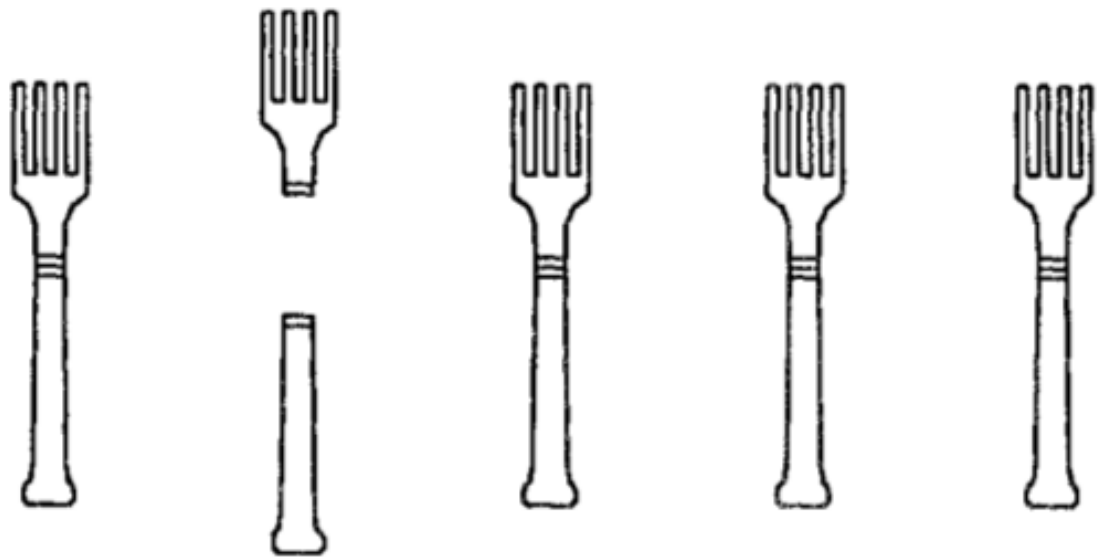


Figure 14: Relevance of integrity in counting (Dehaene 1997, p. 60; adapted from Shipley and Shepperson 1990)

General counting principles

- counting and measuring $\Rightarrow$ independent operations
  - distinct syntax and semantics (Rothstein 2017)
  - counting indicates integrity
  - measuring does not
  - monotonic systems of measurement track part-whole relations (Schwarzschild 2002) $\Rightarrow$ not topological relations
- numeral phrases $\Rightarrow$ counting / measure ambiguity
  - counting $\Rightarrow$ measuring shift
  - possible but restricted

General counting rules

(20) Context: John is cooking with his child. They put three whole apples on a table. John says:

a. There are three apples on the table...
b. Let's count them together: one, two, three.

(21) Context: John is cooking with his child. They sliced three apples and put the slices into a bowl. John says:

a. There are three apples in the bowl...
b. #Let's count them together: one, two, three.

Subatomic quantification

- natural language semantics is sensitive to the fact that objects consist of parts
  - linguistic expressions involving subatomic quantification
  - *whole* adjectives (cf. Morzycki 2002)
  - partitives such as *part* and *half*
  - multipliers such as *double* (Wągiel to appear)
- enhanced mereological structure
  - interaction between $\sqsubseteq$ associated with singularities and pluralities
  - interaction with additional topological relations $\Rightarrow$ different mereotopological structures

Subatomic quantification

- one universal mechanism allowing for counting
  - applicable on different mereotopological levels
  - interaction with specific properties of particular types of entities
- quantification over wholes/parts $\Rightarrow$ identical restrictions
  - principles of non-overlap, maximality, and integrity
  - structured parthood $\Rightarrow$ counting of cognitively salient parts
  - parts $\Rightarrow$ not necessarily topological commitments
  - countability $\Rightarrow$ only integrated entities

Subatomic quantification

- counting of parts
  - counted parts $\Rightarrow$ maximal integrated entities
  - counted parts cannot overlap

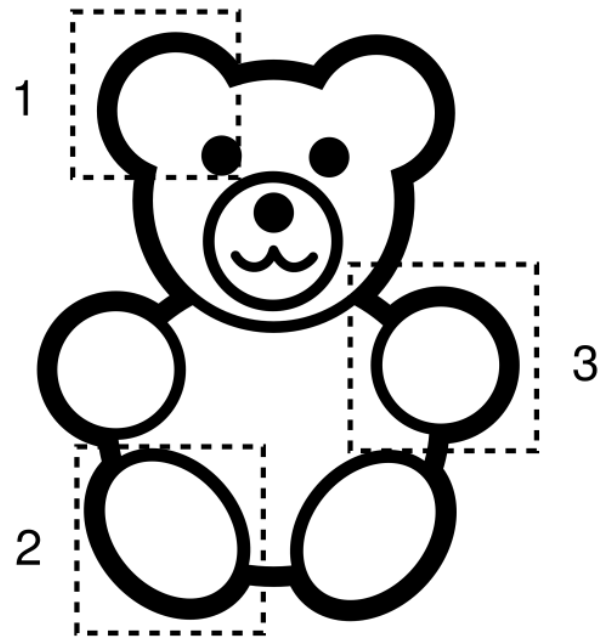


Figure 15: Counting of parts

Subatomic quantification

- illegal counting of parts
  - counting discontinuous parts of an object
  - overlapping parts

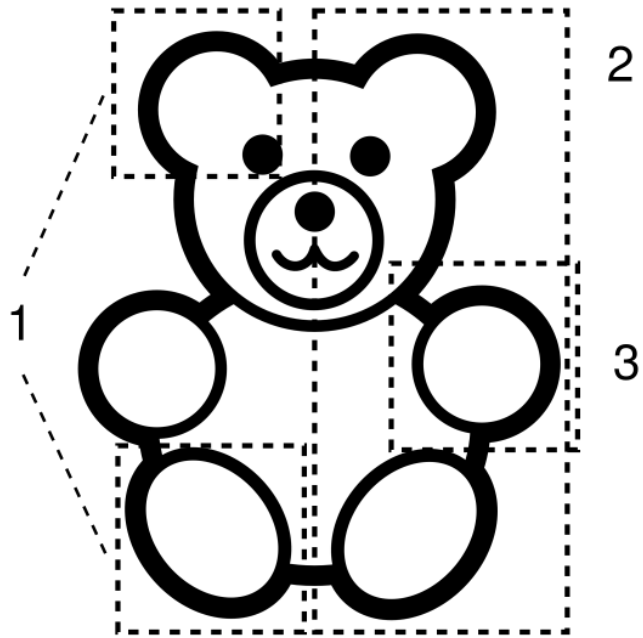


Figure 16: Illegal counting of parts

Partitive expressions

Argument for a unified mereology

- analogy between partitives involving singulars and plurals
  Moltmann (1997, 1998)
- suggests unified part-whole structures

(22) a. Teil des Apfels
part of-the apple$_{\text{GEN}}$
'part of the apple'

b. Teil der Äpfel
part of-the apples
'some of the apples'

Partitive expressions

- in English the analogy does not hold
  Schwarzschild (1996)

(23) a. part of the apple
b. #part of the apples

- systematic ⇒ attested in many languages
  Germanic, Romance, Slavic, Celtic, Finno-Ugric, Semitic, Basque

(24) a. parte del muro
part of-the wall
'part of the wall'
b. parte dei muri
part of-the walls
'some of the walls'

Partitive expressions

- Dutch

(25) a. deel van de appel
part of the apple
'part of the apple'

b. deel van de appels
part of the apples
'some of the apples'

- Russian

(26) a. část' jabloka
part $\text{apple}_{\text{GEN}}$
'part of the apple'

b. část' jablok
part $\text{apples}_{\text{GEN}}$
'some of the apples'

Partitive expressions

- Portuguese

(27) a. parte da maçã
part the apple
'part of the apple'

b. parte das maçãs
part the apples
'some of the apples'

- Irish

(28) a. cuid den úll
part from-the apple
'part of the apple'

b. cuid de na húlla
part from the apples
'some of the apples'

Partitive expressions

- Hungarian

(29) a. az alma egy része
the apple a $\text{part}_{\text{POSS}}$
'part of the apple'

b. az almák egy része
the apples a $\text{part}_{\text{POSS}}$
'some of the apples'

- Hebrew

(30) a. xelek me-ha-baxur
part from-the-boy
'part of the boy'

b. xelek me-ha-baxur-im
part from-the-boy-s
'some of the boys'

Partitive expressions

- Basque

(31) a. sagarraren zati bat
apple$_{\text{GEN}}$ part a
'part of the apple'

b. sagarren zati bat
apples$_{\text{GEN}}$ part a
'some of the apples'

Partitive expressions

- proportional quantifiers and fractions ⇒ similar analogy
- systematic
- cross-linguistically widespread

(32) a. most of the apple
b. most of the apples

(33) a. half of the apple
b. half of the apples

(34) a. two thirds of the apple
b. two thirds of the apples

Partitive expressions

- partitives involving number-neutral expressions
- object mass nouns
- pluralia tantum
- ambiguity between a singular and plural reading
- systematic $\Rightarrow$ attested in many languages

(35) a. část obuvi
part footwear$_{\text{GEN}}$
'part of the footwear/some of the footwear'

b. část nůžek
part scissors$_{\text{GEN}}$
'part of the scissors/some of the scissors'

Partitive expressions

- languages with general number such as Japanese
  Sauerland & Yatsushiro (2004), Watanabe (2013)
- number-neutral nominal
- ambiguity between a singular and plural reading

(36) a. Ringo-no ichibu-ga kusatteiru.
apple-GEN part-NOM is.rotten
'Part of the apple is rotten/Some of the apples are rotten.'

b. Ringo-no hotondo-ga kusatteiru.
apple-GEN most-NOM is.rotten
'Most of the apple(s) is/are rotten.'

Partitive expressions

Counterargument for a unified mereology

Schwarzschild (1996)

- uncountability of *part* words in plural partitives
- only part-of-a-singularity reading
- systematic and cross-linguistically widespread

(37) a. tre parti del muro
three parts of-the wall
'three parts of the wall'

b. #tre parti dei muri
three parts of-the walls
(i) * if counting walls
(ii) ✓ if counting parts of walls

Partitive expressions

- animate nouns ⇒ stronger effects

(38) a. Parte dei ragazzi erano in Texas.
part of-the boys were in Texas
'Some of the boys were in Texas.'

b. #Tre parti dei ragazzi erano in Texas.
three parts of-the boys were in Texas

(39) a. Część chłopców śpi.
part boys_{GEN} sleeps
'Some of the boys sleep.'

b. #Trzy części chłopców śpią.
three parts boys_{GEN} sleep

Partitive expressions

- exhaustive quantifiers and numeric contradictions

(40) a. #Trzy połowy muru są czerwone.
three halves wall_{GEN} are red

b. Trzy połowy murów są czerwone.
three halves $\text{walls}_{\text{GEN}}$ are red
'Three halves of the walls are red.'

(41) a. Obie połowy muru są czerwone.
both halves wall_{GEN} are red
'Both halves of the wall are red.'

b. #Obie połowy murów są czerwone.
both halves $\text{walls}_{\text{GEN}}$ are red

Partitive expressions

Summary of the attested patterns

- interpretative asymmetry in counting environments
- plural partitives ⇒ part-of-a-plurality reading
- count partitives ⇒ only part-of-a-singularity reading

	SINGULARS		PLURALS	
	bare	count	bare	count
subatomic quantification	✓	✓	*	✓
quantification over wholes	*	*	✓	*

Table 1: Properties of partitive words

Partitive expressions

Implications

Schwarzschild (1996)

- Italian and English do not disagree with respect to their ontologies
- singularities and pluralities $\Rightarrow$ two distinct mereological structures
- *part* modeled as an existential 'pieces' quantifier reverse of *each* $\Rightarrow$ selects for plurality-denoting complements

Partitive expressions

Objection

- cardinals do not count pluralities $\Rightarrow$ they count singularities
- domain of quantification $\Rightarrow$ set of atoms
  e.g., Kratzer (1989), Chierchia (1998), Landman (2000)
- *part* words actually pattern with regular nominals

(42) a. three parts of the walls
  (i) #three pluralities of parts of walls
  (ii) plurality of three parts of walls
  b. three walls
  (i) #three pluralities of walls
  (ii) plurality of three walls

Partitive expressions

Zeugma test

cf. Zwicky & Sadock (1975), Lasersohn (1995)

- indeterminacy (non-specificity) $\Rightarrow$ no zeugma effect
- ambiguous expressions $\Rightarrow$ zeugma effect
- *part* $\Rightarrow$ not ambiguous with respect to $\sqsubseteq_m$ and $\sqsubseteq_i$

(43) Ein Teil des Apfels und der Birnen sind
a part the$_{\text{GEN}}$ apple$_{\text{GEN}}$ and the$_{\text{GEN}}$ pears$_{\text{GEN}}$ are
verfault.
rotten
'Part of the apple and some of the pears got spoiled.'

(44) Ein Teil der Birnen und des Apfels sind
a part the$_{\text{GEN}}$ pears$_{\text{GEN}}$ and the$_{\text{GEN}}$ apple$_{\text{GEN}}$ are
verfault.
rotten
'Some of the pears and part of the apple got spoiled.'

Italian irregular plurals

Inflectional class

- morphological and semantic idiosyncrasy
  Acquaviva (2008)
- gender shift in the plural

(45) a. il tuo dito
the$_{\text{MASC.SG}}$ your$_{\text{MASC.SG}}$ finger$_{\text{SG}}$
'your finger'

b. le tue dita
the$_{\text{FEM.PL}}$ your$_{\text{FEM.PL}}$ finger$_{\text{PL}}$
'your fingers'

Italian irregular plurals

- nouns with both regular and irregular counterparts

(46) a. muro ∼ muri ∼ mura
wall$_{\text{MASC.SG}}$ wall$_{\text{MASC.PL}}$ wall$_{\text{FEM.PL}}$
'wall ∼ walls ∼ walls (in a complex)'

b. osso ∼ ossi ∼ ossa
bone$_{\text{MASC.SG}}$ bone$_{\text{MASC.PL}}$ bone$_{\text{FEM.PL}}$
'bone ∼ bones ∼ bones (in a skeleton)'

- irregular forms ⇒ collectivizers (Ojeda 1995) or inherently encoding cohesion of referents (Acquaviva 2008)
- arguably a notion of connectedness of parts is involved

Italian irregular plurals

Observation

- partitives with irregular plurals $\Rightarrow$ compatible with cardinals
- quantification over parts of singularities or pluralities

(47) tre parti delle mura
three parts of-the $\text{wall}_{\text{COLL}}$
'three parts of the complex formed by the walls'

(i) ✓ if counting parts of walls
(ii) ✓ if counting individual walls
(iii) ✓ if counting continuous pluralities of walls

Italian irregular plurals

(48) tre parti delle ossa
three parts of-the $\text{bone}_{\text{COLL}}$
'three parts of the skeleton formed by the bones'

(i) ✓ if counting bones
(ii) ✓ if counting parts of bones
(iii) ✓ if counting continuous pluralities of bones,
femur + knee, ulna + radius, and skull + neck

Italian irregular plurals

Italian partitives

- interaction between partitivity and number
- quantification over wholes
- subatomic quantification
- countability

	SINGULARS		REGULAR PL		IRREGULAR PL	
	bare	count	bare	count	bare	count
subatomic quantification	✓	✓	*	✓	✓	✓
quantification over wholes	*	*	✓	*	✓	✓

Table 2: Properties of Italian *parte* 'part'

Italian irregular plurals

Explanation

- interaction between partitives and number ⇒ (un)countability
- regular plurals ⇒ no topological relations between parts
  - parts of a plurality do not form an integrated entity
  - multiple overlapping parts of a plurality
  - violation of the general counting rules ⇒ uncountability
- irregular plurals ⇒ connected parts
  - parts of a plurality form a cohesive whole
  - counting is possible as long as it operates on integrated objects

Italian irregular plurals

Conclusions

- *part* words can operate both at the atomic and subatomic level of a part-whole structure
- partitives employ a general parthood relation
- countability results from the interaction between the meaning of a *part* word and the meaning of a singular or plural NP
- only integrated parts (proper or improper) of integrated wholes can be assigned a number when counting

Polish *half* words

Three distinct expressions

- morphologically derived from one another

(49) a. pół
root
'half$_1$'

b. poł-ow-a
root-derivational.suffix-inflectional.marker
'half$_2$'

c. poł-ów-k-a
root-derivational.suffix$_1$-deriv.suffix$_2$-infl.marker
'half$_3$'

Polish *half* words

- *pół* $\Rightarrow$ incompatible with cumulative predicates

(50)
a. pół jabłka
half$_1$ apple$_{\text{GEN}}$
'half of the apple'

b. pół stosu (jabłek)
half$_1$ pile$_{\text{GEN}}$ (apples$_{\text{GEN}}$)
'half of the pile (of apples)'

c. #pół jabłek
half$_1$ apples$_{\text{GEN}}$

d. #pół soku
half$_1$ juice$_{\text{GEN}}$

Polish *half* words

- *połowa* $\Rightarrow$ no distributional restrictions

(51)
a. połowa jabłka
half$_2$ apple$_{\text{GEN}}$
'half of the apple'

b. połowa stosu (jabłek)
half$_2$ pile$_{\text{GEN}}$ (apples$_{\text{GEN}}$)
'half of the pile (of apples)'

c. połowa jabłek
half$_2$ apples$_{\text{GEN}}$
'half of the apples'

d. połowa soku
half$_2$ juice$_{\text{GEN}}$
'half of the juice'

Polish *half* words

- *połówka* $\Rightarrow$ compatible only with regular concrete singulars

(52)
a. połówka jabłka
   half_3 $\text{apple}_{\text{GEN}}$
   'half of the apple'

b. #połówka stosu (jabłek)
   half_3 pile_{GEN} ($\text{apples}_{\text{GEN}}$)

c. #połówka jabłek
   half_3 $\text{apples}_{\text{GEN}}$

d. #połówka soku
   half_3 $\text{juice}_{\text{GEN}}$

Polish *half* words

Distribution of Polish *half* expressions

- three distinct categories
- collectives $\Rightarrow$ put aside
- sensitivity to topological notions

	SINGULARS	COLLECTIVES	PLURALS	MASS NOUNS
połowa	✓	✓	✓	✓
pół	✓	✓	*	*
połówka	✓	*	*	*

Table 3: Distribution of Polish *half*-words

Polish *half* words

Observation

- available extensions of partitives differ ⇒ topological sensitivity

(53)
a. pół jabłka
half$_1$ apple$_{\text{GEN}}$
'half of the apple' ✓ cont.part / ✓ discont.part

b. połowa jabłka
half$_2$ apple$_{\text{GEN}}$
'half of the apple' ✓ cont.part / ✓ discont.part

c. połówka jabłka
half$_3$ apple$_{\text{GEN}}$
'half of the apple' ✓ cont.part / # discont.part

Polish *half* words

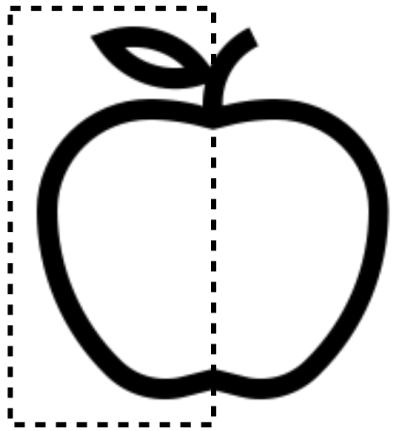


Figure 17: Continuous half

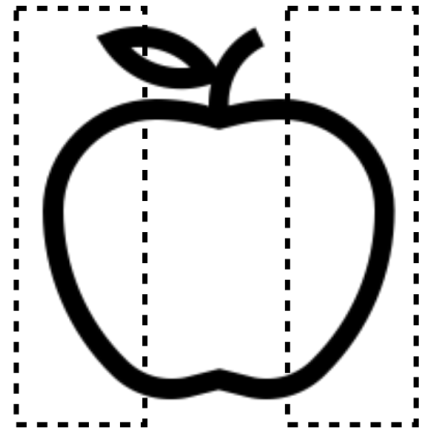


Figure 18: Discontinuous half

	CONTINUOUS PART	DISCONTINOUS PART
połowa	✓	✓
pół	✓	✓
połówka	✓	*

Table 4: Denotations of Polish *half*-words

Polish *quarter* words

More evidence

- Polish *quarter*-words ⇒ topological sensitivity

	SINGULARS	COLLECTIVES	PLURALS	MASS NOUNS
jedna czwarta	✓	✓	✓	✓
ćwierć	✓	✓	*	*
ćwiartka	✓	*	*	*

Table 5: Distribution of Polish *quarter*-words

	CONTINUOUS PART	DISCONTINOUS PART
jedna czwarta	✓	✓
ćwierć	✓	✓
ćwiartka	✓	*

Table 6: Denotations of Polish *quarter*-words

Cross-linguistic perspective

Diagnostics to detect topology-sensitive partitive expressions

- the flag test
- continuous vs. discontinuous parts
- easily distinguishable properties

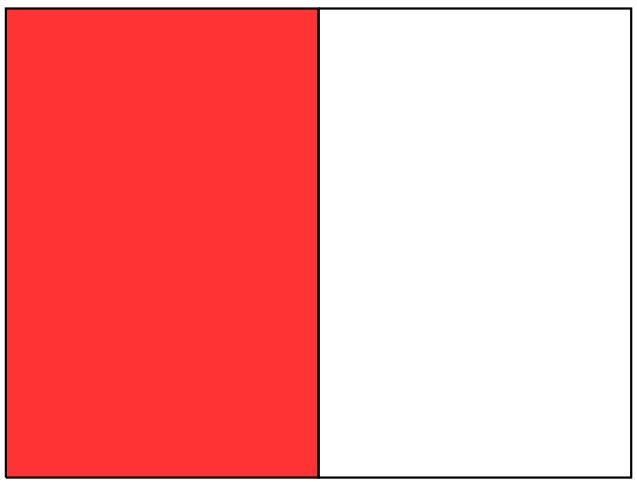


Figure 19: Flag AB

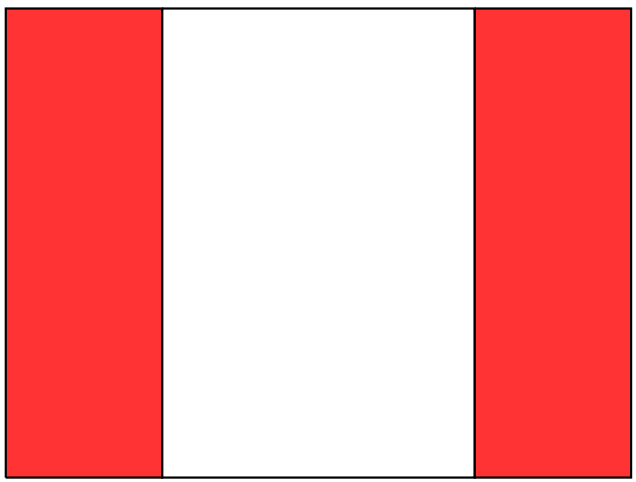


Figure 20: Flag ABA

Cross-linguistic perspective

Different structures ⇒ similar semantic effect cross-linguistically

- English

(54) a. Half the flag is red.
  (i) AB
  (ii) ABA

b. A half of the flag is red.
  (i) AB
  (ii) #ABA

Cross-linguistic perspective

- German

(55) a. Die Hälfte von der Fahne ist rot.
the half of the flag is red
'Half the flag is red.'
(i) AB
(ii) ABA

b. Die eine Hälfte der Fahne ist rot.
the a/one half of-the flag is red
'The half of the flag is red.'
(i) AB
(ii) #ABA

Cross-linguistic perspective

- Dutch

(56) a. De helft van de vlag is rood.
the half of the flag is red
'Half the flag is red.'
(i) AB
(ii) ABA

b. De halve vlag is rood.
the half flag is red
'The half of the flag is red.'
(i) AB
(ii) #ABA

Cross-linguistic perspective

- Portuguese

(57) a. Metade da bandeira é vermelha.
half the flag is red
'Half the flag is red.'
(i) AB
(ii) ABA

b. Meia bandeira é vermelha
half flag is red
'A half of the flag is red.'
(i) AB
(ii) #ABA

Cross-linguistic perspective

- Mandarin

(58) a. guó qí de yí-bàn shì hóng de.
national flag DE one-half COP red DE
'Half the national flag is red.'
(i) AB
(ii) ABA

b. bàn-miàn guó qí shì hóng de.
half-CL national flag COP red DE
'A half of the national flag is red.'
(i) AB
(ii) #ABA

Multipliers

Neglected class of numerical expressions

- cross-linguistically widespread category
- attested also in non-IE languages

(59)

a.	double	
b.	doppelt	German
c.	doppio	Italian
d.	dvojnoj	Russian
e.	dvigubas	Lithuanian
f.	dupla	Hungarian
g.	shuāng	Mandarin

Multipliers

Expressions dedicated to counting parts

- entailment $\Rightarrow$ complex inner structure

(60) a. The Pschent is a double crown.
b. $\models$The Pschent consists of two parts.

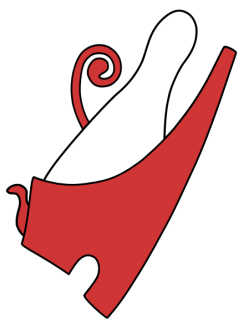


Figure 21: Pschent

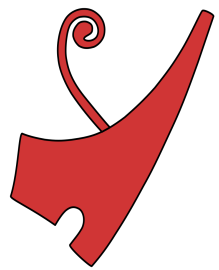


Figure 22: Deshret

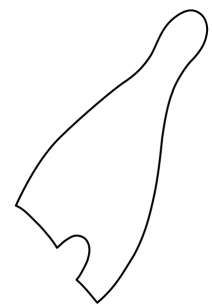


Figure 23: Hedjet

Multipliers

More examples

- some frequent collocates in COCA

(61)
a. double bracket
b. double sink
c. double tomb
d. double canoe
e. double flute
f. double chin
g. double layer
h. double glazing
i. double rainbow
j. double star
k. double hamburger
l. double shotgun

Multipliers

Non-trivial quantificational behavior

- quantification over parts rather than wholes
- adjectival properties
- modified NPs $\Rightarrow$ always countable (Universal Packager)

(62) a. three crowns
b. three double crowns

(63) a. #three coffees
b. three double coffees

Multipliers

Relationship between multipliers and cardinals

- Slavic and Baltic multipliers ⇒ derived from numeral roots
- multiplicative affix ⇒ classifier

(64) a. dv-a
numeral.root-infl.marker
'two' Russian

b. dv-oj-n-oj
numeral.root-stem-mult.suffix-infl.marker
'double' Russian

Multipliers

- Slavic and Baltic multipliers

(65) a. dwa — Polish
b. podwójny

(66) a. dva — Czech
b. dvojitý

(67) a. dva — BCS
b. dvostruki

(68) a. du — Lithuanian
b. dvigubas

Multipliers

Quantification over cognitively salient parts

- self-sufficient parts ⇒ property comparable to the whole
- essential parts

Possible extensions

- mass nouns ⇒ quantification over parts of portions
- event nominals ⇒ parts of events
- role nouns ⇒ parts of roles
  Zobel (2017)

(69) a. double vodka
b. double murder
c. double agent

Data summary

Cross-linguistic distribution of partitives

- singulars and plurals $\Rightarrow$ unified part-whole structures
- differences $\Rightarrow$ topological notions

Italian irregular plurals

- countability $\Rightarrow$ sensitive to integrity
- both at the subatomic and superatomic level

Polish *half* words

- topological sensitivity
- expressed formally

Multipliers

- numerical expressions devised to count parts
- identical constraints on counting

Analysis

Count nouns

- $\textsc{mssc}$ entities $\Rightarrow$ integrated wholes $\Rightarrow$ no atomicity

(70) Count noun
$[\![\text{apple}]\!] = \lambda x[\textsc{mssc}(\textsc{apple})(x)]$

Pluralization

- presupposition $\Rightarrow$ $\textsc{mssc}$ predicates
- algebraic closure (Link 1983)
- no topological constraints

(71) $[\![\text{PL}]\!] = \lambda P \,.\, P_{\textsc{mssc}}[^*P]$

(72) $[\![\text{apples}]\!] = [\![\text{PL}]\!]([\![\text{apple}]\!]) =$
$\lambda x\Big[^*\Big(\lambda y[\textsc{mssc}(\textsc{apple})(y)]\Big)(x)\Big]$

Analysis

Cardinals

- complex expressions ⇒ derived from numeral roots
- predicate modifiers
  Ionin & Matushansky (2006), Chierchia (2010)
- classifier semantics ⇒ shift from names of numbers
  Rothstein (2013), Sudo (2016)
- classifier $\mathsf{CL}_{\#}$ ⇒ measure function $\#(P)$
- require $\textsc{mssc}$ predicates ⇒ counts integrated wholes

(73) Measure function $\#(P)$
$\forall P \forall x[\#(P)(x) = 1 \text{ iff } \textsc{mssc}(P)(x)]$

(74) Cardinal numeral
$[\![\text{two}]\!] = [\![\mathsf{CL}_{\#}]\!]([\![\sqrt{tw}]\!]) =$
$\lambda P.\ P_{\textsc{mssc}}\ \lambda x[{}^{*}P(x) \wedge \#(P)(x) = 2]$

Analysis

Multipliers

- complex expressions $\Rightarrow$ derived from numeral roots
- names of numbers $\Rightarrow$ predicate modifiers
- classifier $\mathrm{CL}_{\boxplus}$ $\Rightarrow$ measure function $\boxplus(P)$
- count essential parts of $\textsc{mssc}$ entities

(75) Measure function $\boxplus(P)$
$\forall P \forall x[\boxplus(P)(x) = 1$ iff
$\textsc{mssc}(P)(x) \wedge \exists y[y \sqsubseteq x \wedge \textsc{essential}(P)(y) \wedge \#(y) = 1]]$

(76) Polish multiplier
$[\![\text{podwójny}]\!] = [\![\mathrm{CL}_{\boxplus}]\!]([\![\sqrt{dw}]\!]) =$
$\lambda P.\ P_{\textsc{mssc}}\ \lambda x[P(x) \wedge \boxplus(P)(x) = 2]$

Analysis

Partitives

- partitive constraint $\Rightarrow$ entity-denoting embedded DP
- *part* words
  - partitivity $\Rightarrow$ proper parthood (Barker 1998)
- *half* words
  - vague $\Rightarrow$ correspond to $\approx 50\%$
  - contextually conditioned measure function μ similar to *more* (Bale & Barner 2009)
  - different measures for different NPs $\Rightarrow$ number, volume

(77) $[\![\text{PART}]\!] = \lambda y \lambda x[x \sqsubset y]$

(78) $[\![\text{HALF}]\!] = \lambda y \lambda x[x \sqsubset y \wedge \mu(x) \approx \mu(y) \times 0.5]$

Analysis

Partitioning

- partitioning function $\pi \Rightarrow$ non-overlap
- relative atomicity $\Rightarrow$ irrelevant
- multiple possible partitions

(79) Partitioning function π
for any P and any x and y in $\pi(P)$
$\neg\exists z[z \sqsubseteq x \wedge z \sqsubseteq y]$

Individuation

- individuation of parts $\Rightarrow$ non-overlap + integrity
- individuating element IND $\Rightarrow \pi + \textsc{mssc}$

(80) Individuating element
$[\![\text{IND}]\!] = \lambda P \lambda x[\textsc{mssc}\Big(\pi(P)\Big)(x)]$

Analysis

Partitive words

- bare partitivity $\Rightarrow$ topological neutrality
- interaction $\Rightarrow$ topological sensitivity, individuation

(81) German topology-neutral *part* word *Teil*
$[\![\text{Teil}]\!] = \lambda y \lambda x[x \sqsubset y]$

(82) Polish topology-neutral *half* word *połowa*
$[\![\text{połowa}]\!] = \lambda y \lambda x[x \sqsubset y \wedge \mu(x) \approx \mu(y) \times 0.5]$

(83) Polish topology-sensitive *half* word *pół*
$[\![\text{pół}]\!] = \lambda y \,.\, y_{\text{MSSC}}\ \lambda x[x \sqsubset y \wedge \mu(x) \approx \mu(y) \times 0.5]$

(84) Polish individuating suffix *-k-*
$[\![\text{-k-}]\!] = [\![\text{IND}]\!] = \lambda P \lambda x[\text{MSSC}\Big(\pi\big(P\big)\Big)(x)]$

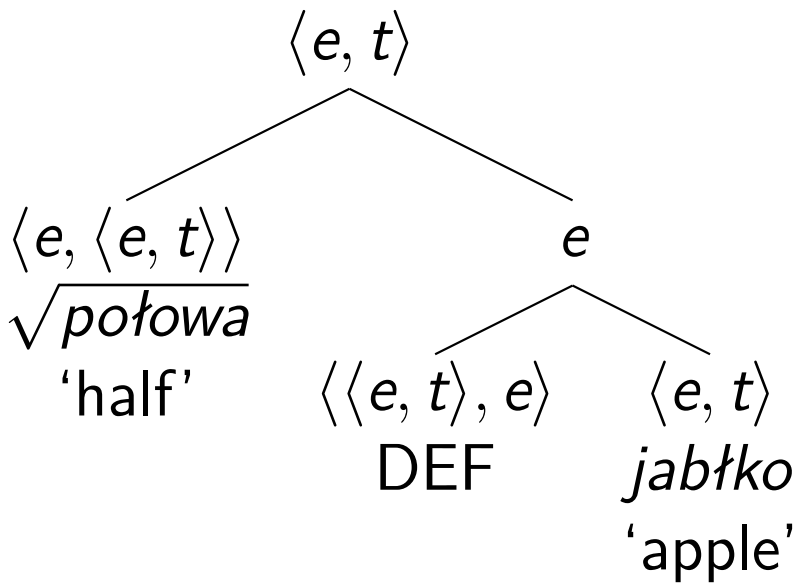
(85) Polish individuating *half* word *połówka*
$[\![\text{połówka}]\!] = [\![\text{-k-}]\!]([\![\text{pół}]\!])$

Analysis

Polish topology-neutral proportional partitive

(86) połowa jabłka
half apple$_{\text{GEN}}$

(87)

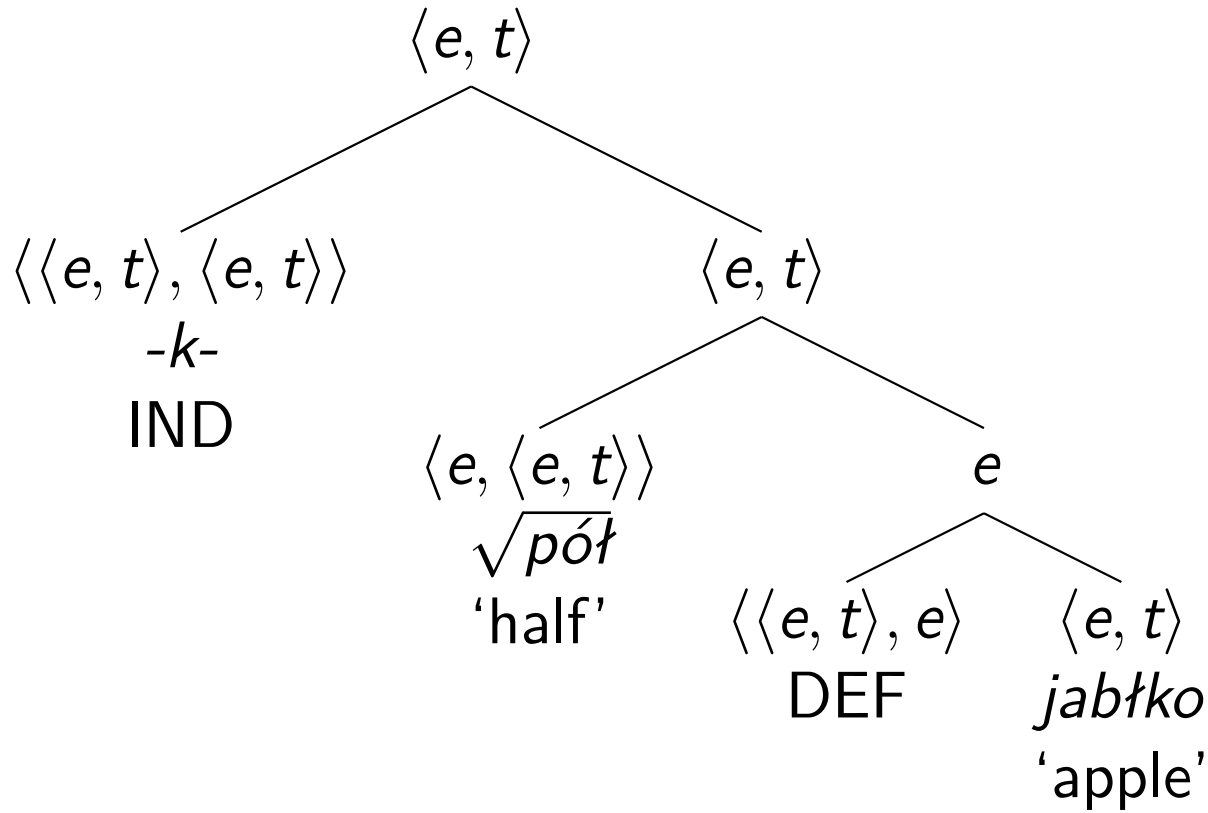


Analysis

Polish topology-sensitive proportional partitive

(88) połówka jabłka
half-k apple$_{\text{GEN}}$

(89)

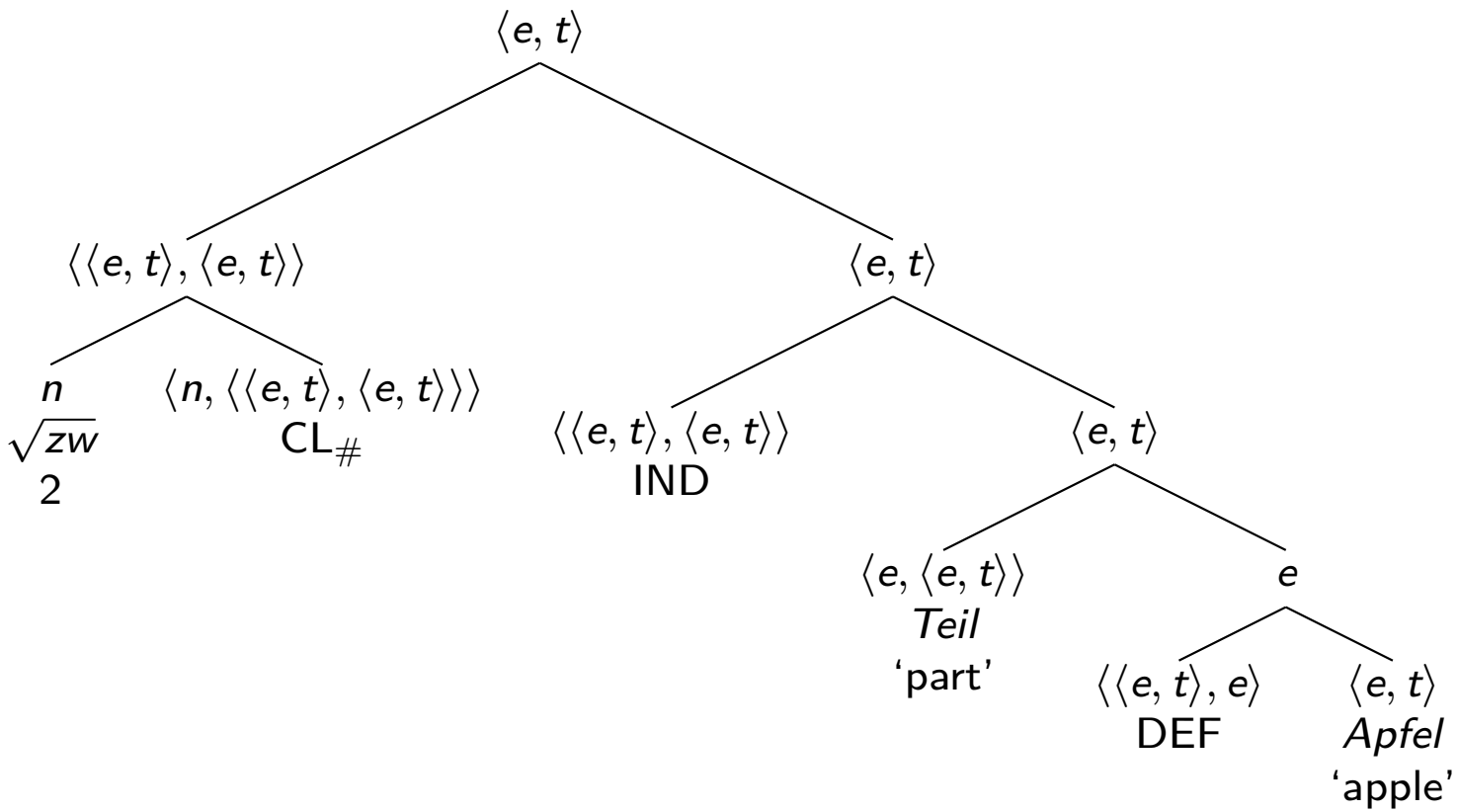


Analysis

German count explicit partitive

(90) zwei Teile des Apfels
two parts the$_{\text{GEN}}$ apple$_{\text{GEN}}$

(91)

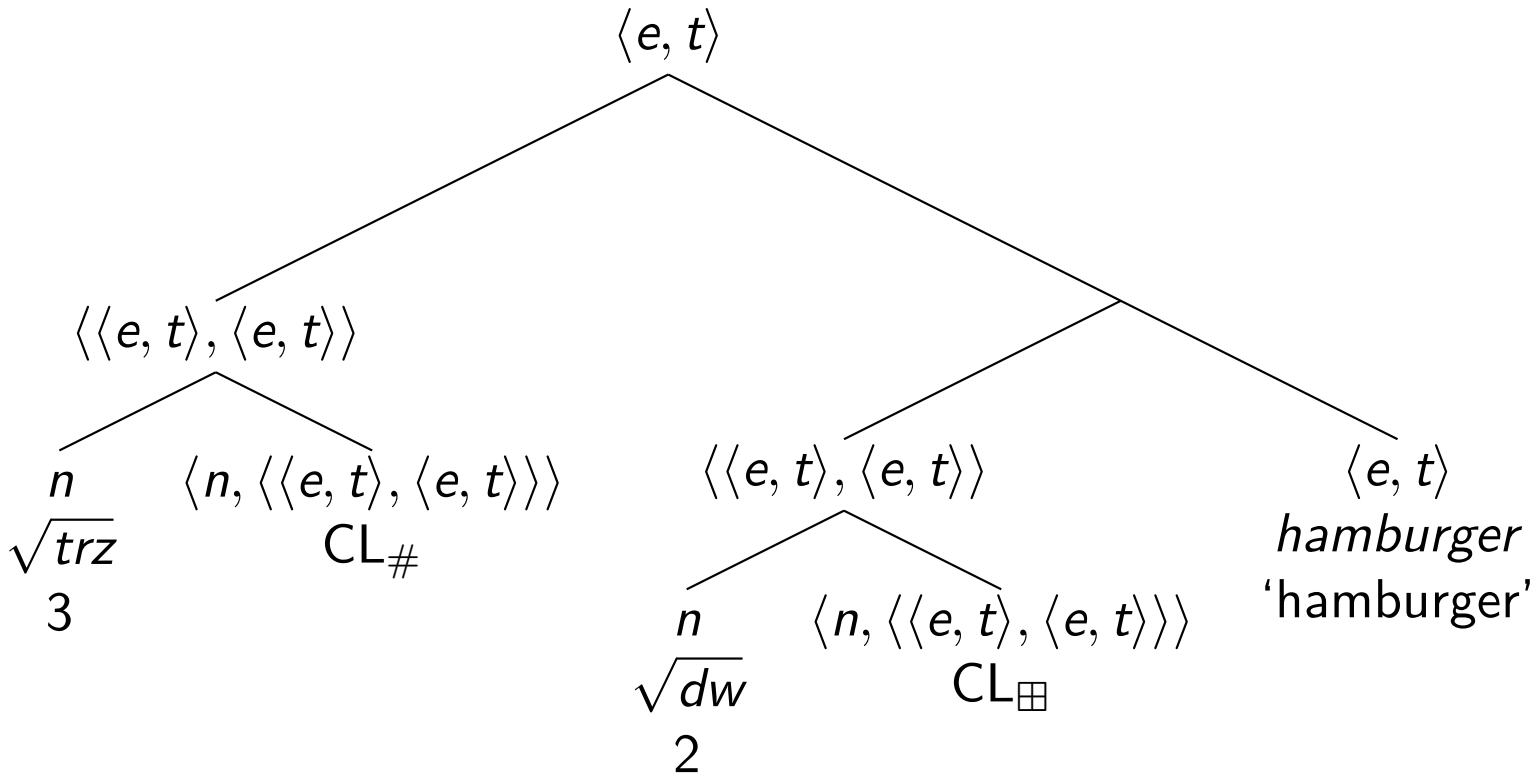


Analysis

Polish multiplier phrase modified by the cardinal

(92) trzy podwójne hamburgery
three double hamburgers

(93)



Conclusion

Claims

- NL semantics $\Rightarrow$ sensitive to subatomic part-whole structures
- quantification over parts and wholes $\Rightarrow$ identical restrictions
- counting $\Rightarrow$ presupposes particular topological relations

Countability

- only integrated parts of integrated wholes $\Rightarrow$ number
  - improper $\Rightarrow$ quantification over wholes
  - proper $\Rightarrow$ subatomic quantification

Conclusion

Novel evidence

- cross-linguistic distribution of partitives
- Italian irregular plurals
- Polish *half* words
- multipliers

Consequences

- mereotopological approach
- generalized system of quantification
- classifier semantics for numeral expressions

Conclusion

Further investigation

- more expressions sensitive to subatomic parthood
  - adjectives such as *whole*, *entire*, *complete*
  - adverbs such as *wholly*, *partially*
  - verbs of separation such as *dismember*, *dismantle*
- cross-linguistic investigation
  - English: *part of* $\sim$ *a part of*, *half of* $\sim$ *half a(n)*
  - German: *halb* $\sim$ *Hälfte*
  - French: *part* $\sim$ *partie*
- structured parthood

References

Acquaviva, P. (2008). *Lexical Plurals: A Morphosemantic Approach*. Oxford University Press, Oxford.

Bach, E. (1986). The algebra of events. *Linguistics and Philosophy*, 9(1):5–16.

Bale, A. C. and Barner, D. (2009). The interpretation of functional heads: Using comparatives to explore the mass/count distinction. *Journal of Semantics*, 26(3):217–252.

Barker, C. (1998). Partitives, double genitives and anti-uniqueness. *Natural Language & Linguistic Theory*, 16(4):679–717.

Boisvert, M., Standing, L., and Moller, L. (1999). Successful part-whole perception in young children using multiple-choice tests. *The Journal of Genetic Psychology*, 160(2):167–180.

Casati, R. and Varzi, A. C. (1999). *Parts and Places: The Structures of Spatial Representation*. MIT Press, Cambridge, MA.

Champollion, L. (2010). *Parts of a Whole: Distributivity as a Bridge between Aspect and Measurement*. PhD thesis, University of Pennsylvania.

Chierchia, G. (2010). Mass nouns, vagueness and semantic variation. *Synthese*, 174(1):99–149.

Dehaene, S. (1997). *The Number Sense: How the Mind Creates Mathematics*. Oxford University Press, New York, NY.

Elkind, D., Koegler, R. R., and Go, E. (1964). Studies in perceptual development: Ii. part-whole perception. *Child Development*, pages 81–90.

Grimm, S. (2012). *Number and Individuation*. PhD thesis, Stanford University, California.

Grimm, S. and Dočekal, M. (to appear). Counting aggregates, groups and kinds: Countability from the perspective of a morphologically complex language. In *Counting and Measuring Across Languages.* Cambridge University Press, Cambridge.

Henderson, R. (2017). Swarms: Spatiotemporal grouping across domains. *Natural Language & Linguistic Theory*, 35(1):161–203.

Ionin, T. and Matushansky, O. (2006). The composition of complex cardinals. *Journal of Semantics*, 23(4):315–360.

References

Kimchi, R. (1993). Basic-level categorization and part-whole perception in children. *Bulletin of the Psychonomic Society*, 31(1):23–26.

Krifka, M. (1989). Nominal reference, temporal constitution and quantification in event semantics. In Bartsch, R., van Benthem, J., and von Emde Boas, P., editors, *Semantics and Contextual Expression*, pages 75–115. Foris Publications, Dordrecht.

Landman, F. (2011). Count nouns – mass nouns, neat nouns – mess nouns. *Baltic International Yearbook of Cognition, Logic and Communication*, 6(1):12.

Landman, F. (2016). Iceberg semantics for count nouns and mass nouns: Classifiers, measures and portions. *Baltic International Yearbook of Cognition, Logic and Communication*, 11(1):6.

Lasersohn, P. (1995). *Plurality, Conjunction and Events*. Kluwer Academic Publishers, Boston.

Link, G. (1983). The logical analysis of plural and mass nouns: A lattice–theoretical approach. In Bäuerle, R., Schwarze, C., and von Stechow, A., editors, *Meaning, Use, and Interpretation of Language*, pages 302–323. Mouton de Gruyter, Berlin.

Moltmann, F. (1997). *Parts and Wholes in Semantics*. Oxford University Press, New York, NY.

Moltmann, F. (1998). Part structures, integrity, and the mass-count distinction. *Synthese*, 116(1):75–111.

Morzycki, M. (2002). Wholes and their covers. In Jackson, B., editor, *Proceedings of Semantics and Linguistic Theory 12*, pages 184–203. CLC Publications, Ithaca, NY.

Ojeda, A. E. (1995). The semantics of the Italian double plural. *Journal of Semantics*, 12(3):213–237.

Pianesi, F. (2002). Friederike Moltmann, 'Parts and Wholes in Semantics'. *Linguistics and Philosophy*, 25(1):97–120.

Rothstein, S. (2013). A Fregean semantics for number words. In Aloni, M., Franke, M., and Roelofsen, F., editors, *Proceedings of the 19th Amsterdam Colloquium*, pages 179–186.

Rothstein, S. (2017). *Semantics for Counting and Measuring*. Cambridge University Press, Cambridge.

Sauerland, U. and Yatsushiro, K. (2004). A silent noun in partitives. In Moulton, K. and Wolf, M., editors, *Proceedings of the North East Linguistic Society 34*, pages 505–516. GLSA, Amherst, MA.

References

Schwarzschild, R. (1996). *Pluralities*. Kluwer Academic Publishers, Dordrecht.

Schwarzschild, R. (2002). The grammar of measurement. In Jackson, B., editor, *Proceedings of Semantics and Linguistic Theory 12*, pages 225–245. CLC Publications, Ithaca, NY.

Shipley, E. F. and Shepperson, B. (1990). Countable entities: Developmental changes. *Cognition*, 34(2):109–136.

Sudo, Y. (2016). The semantic role of classifiers in Japanese. *Baltic International Yearbook of Cognition, Logic and Communication*, 11(1):1–15.

Sutton, P. R. and Filip, H. (2017). A probabilistic, mereological account of the mass/count distinction. In Hansen, H. H., Murray, S. E., Sadrzadeh, M., and Zeevat, H., editors, *Logic, Language, and Computation. 11th International Tbilisi Symposium on Logic, Language, and Computation, TbiLLC 2015, Tbilisi, Georgia, September 21-26, 2015*, pages 146–170. Springer, Berlin.

Varzi, A. C. (2016). Mereology. In Zalta, E. N., editor, *The Stanford Encyclopedia of Philosophy*. Metaphysics Research Lab, Stanford University.

Wągiel, M. (to appear-a). Entities, events, and their parts: The semantics of multipliers in Slavic. In Radeva-Bork, T. and Kosta, P., editors, *Current Developments in Slavic Linguistics: Twenty Years After*. Peter Lang, Frankfurt am Main.

Watanabe, A. (2013). Count syntax and the partitivity. In *19th ICL Papers*, pages 1–18. Département de Linguistique de l'Université de Genève, Geneva.

Zobel, S. (2017). The sensitivity of natural language to the distinction between class nouns and role nouns. In *Proceedings of Semantics and Linguistic Theory 27*, pages 438–458. CLC Publications, Ithaca, NY.

Zwicky, A., Sadock, J., and Kimball, J. (1975). Ambiguity tests and how to fail them. In Kimball, J. P., editor, *Syntax and Semantics*, pages 1–36. Academic Press, New York, NY.