Lexical Semantics

1- Introduction to LS
LS, Formal Semantics & Ontology
2- LS in Computational Linguistics
Specific lexical resources and lexicons

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Introduction: Role of the lexicon in semantics

- In classical formal semantics (Montague Grammar, standard DRT), very limited
  - A few types and classes: human/non human (pronominal anaphora), mass/count, singular/collective/kind (determiners), aktionsarten (tense and temporal modifiers)…
- Focus on the logical structure of sentences
  un chat mange un rat ≈ *un chat observe un rat* ≈ *un rat mange un chat* ≈ …
  $\exists x \exists y\ (P(x) \wedge Q(y) \wedge R(x,y))$
- Meaning of predicates is the job of the interpretation function
- BUT…

Evidence that lexical contents matters

- Composition
  - Type restriction in predication
    ??Colorless green ideas sleep furiously
    ??The number two is (not) soft
    ➢ physical object, material object, event, animate entity, artefact, abstract entity, location…
  - Coercion
    to finish requires an event
    John finished the novel >>
    John finished writing / reading the novel (abstract entity)
    The goat finished the novel >>
    The goat finished eating the novel (physical object)
    A rock (physical object) / *A good rock* (artefact)

Evidence that lexical contents matters

- Anaphora resolution: definite descriptions, bridging anaphora
  Jean caresse le chat. L'animal est grognon. Il couche les oreilles.
- Presupposition
  Le chat a tué le rat presupposes *le rat était vivant*
  John left presupposes *John was here*

Evidence that lexical contents matters

- Discourse coherence
  John pushed Max. Mary laughed.
  John pushed Max. #Mary wrote a poem.
  John pushed Max. He fell.
  John pushed Max. He laughed.
  John pushed Max. #He wrote a poem.

Outline - Part 1

- What belongs to the lexicon
- Which lexicon for which purpose
- Lexicon representations
- The need for formal ontology
- An example: part-whole relations

What's in a lexicon

- Content words, open classes
  - N, V, Adj
  - Adv: *néanmoins, alors, puis…* ? (compare with: *mais, donc, or*…)
  - P: *dans, sur, après, devant*… ?
- Grammaticalization degree
- Distribution varies across languages

Which lexicon for what purpose?

- Linguistics
  - Analyzing regularities within the lexicon
  - Analyzing lexicon-dependant semantic and pragmatic phenomena
- NLP
  - Information retrieval
  - Question answering
  - Machine translation
  - Reference resolution

  …

Important regularities

- Copredication: polysemy

  The lunch was delicious but took forever: food & event?

  ➢ Dot objects, complex types
- Verb alternations (causative)

  Le chat a cassé la branche - la branche a cassé

  *Le chat a cogné/griffé la branche - *la branche a cogné/griffé*

  Il a vidé la cuve - la cuve s'est vidée

  ➢ Change-of-state verbs & surface-contact verbs

  ➢ Result verbs & manner verbs

Different questions, different focus

- How is the lexicon structured
  - Semantic relations between lexical items (hyponymy, synonymy, antonymy, meronymy…)
  - Lexical classes (e.g., manner verbs, result verbs…)
  - Polysemy (*lunch*: food / event / time), denominal or deadjectival verbs, deverbal nouns…

Lexical relations

- Hyponymy / hypernymy — focus on nouns

  … *Chaise - Siège - Meuble* … — $P(x) \rightarrow Q(x)$, "is-a" relation
- Synonymy

  Livre - Bouquin — $P(x_1, \ldots x_i) \leftrightarrow Q(x_1, \ldots x_i)$ (context appropriateness?)
- Antonymy

  Vivant - Mort, Bon - Mauvais — $P(x_1, \ldots x_i) \leftrightarrow \neg Q(x_1, \ldots x_i)$ (type restrictions?, graduality?)

  Other oppositions? e.g. *vendre - acheter, abimer - réparer*
- Meronymy / holonymy — focus on nouns

  Roue - Voiture, Doigt - Main, Noyau - Cellule

  Formula(s) involving parthood relation(s)

Different questions, different focus

- How is the lexicon structured
- What's in a lexical entry to account for:
  - Type restriction, coercion, copredication
  - Verb alternation
  - Anaphora resolution, discourse understanding

  ➢ Lexical vs. Common-sense vs. Ontological knowledge?

  ➢ Universal meaning primitives?

Different questions, different focus

- How is the lexicon structured
- What's in a lexical entry
- How do we build a lexicon
  - From scratch or automatically (from text)?
  - Which evidence, which method?
    - Truth conditions and inference
    - Substitution
    - Co-occurrence (within patterns)
  - ➢ Structuralism or referential semantics?

Shallow vs. deep representations

Lexical resources (specialized or general) vs. Lexicons

- Taxonomy (hyponymy / hypernymy)
- Thesaurus (hyponymy, synonymy, antonymy, meronymy…)
- Argument structure, type restriction, semantic roles
- Feature structure, event causal structure
- Decomposition of word senses into meaning primitives, cognitive semantics
- Full sense definitions within a logical theory supporting inference

Basis for deeper representations

- Meaning primitives
  - Causation: Cause
  - Change: Become, Change, Go, Transition
  - State: Be
  - Telicity: Goal, Source, Path
  - Agency: Act, Do…
- Full senses: core domains and formal relations
  - Space, time, matter, mental attitudes, agency…
  - Parthood, participation, dependence, causation…

Some well-known works

- **Study of lexical relations**: Lyons, Cruse…
- **Thesaurus**: WordNet (Fellbaum, Miller)
- **Argumental structure**: Frame semantics, FrameNet (Fillmore)
- **Feature Structure, polysemy**: Generative Lexicon, "qualia" structure (Pustejovsky)
- **Meaning decomposition**: Jackendoff, Levin, Talmy, Vandeloise, Wierzbicka…
- **Reasoning**: Hobbs

The pervasive need for Formal Ontology

- Types and top-level concepts
  - what are the basic types (categories) / top-level concepts, what are complex types?
  - ➢ DOLCE & OntoWordNet
  - ➢ Logic of complex types and dot objects (Asher)
- Structural relations
  - which ones, i.e., which formal properties?
  - ➢ Parthood relations
- Meaning and core domain primitives, formal relations
  - which ones, i.e., what's their own meaning, how are they axiomatized?
  - ➢ Semantics of time, semantics of space

Parthood relations, between semantics and ontology

- Meronymy

  engine-car, cuff-sleeve, wall-house, finger-hand, head-committee…
- (Lexical) semantics

  the engine is part of the car, the door has a handle, the front of the car, a cow from the herd, this syrup is made of water and sugar…
- Mereology

Meronymy

- Which relation?
- Assuming a parthood relation *P*, which formula?
  - Hyponymy: $Q(x) \rightarrow R(x)$
  - Meronymy / holonymy:
    - $(Q(x) \wedge R(y)) \rightarrow P(x,y)$??
    - $Q(x) \rightarrow \exists y\,(R(y) \wedge P(x,y))$ holonymy?
    - $R(y) \rightarrow \exists x\,(Q(x) \wedge P(x,y))$ meronymy?
- *roue-voiture, doigt-main, poignée-porte?*

Mereology

- Formal relation of Parthood
- Generic relation: search for invariants across domains
- One of the pillars of formal ontology
  - Basic structure for concepts (unary predicates): taxonomic "is-a" relation ($\rightarrow$)
  - Basic structure for entities: parthood (*P*)
    my hand-my body, today-this week,
    this room-the university, one student-the class,
    mereology-formal ontology…

A Bit of History

- Lesniewski 1927-1931, *On the Foundations of Mathematics*
- Tarski 1935, link with Boolean algebra
- Leonard & Goodman 1940, the "calculus of individuals", a first-order theory
- Contemporary studies: Peter Simons (1986), Achille Varzi (1996)
- All 'ontologies' use a parthood relation, in the best cases fully specified with respect to Simons's work

Basic Mereology

- P, partial order:

(M1)	$\forall x\, P(x,x)$	Reflexivity
(M2)	$\forall xyz\, ((P(x,y) \wedge P(y,z)) \rightarrow P(x,z))$	Transitivity
(M3)	$\forall xy\, ((P(x,y) \wedge P(y,x)) \rightarrow x=y)$	Antisymmetry

- Definitions

$PP(x,y) =_{df}\ P(x,y) \wedge \neg P(y,x)$	Proper part
$O(x,y) =_{df}\ \exists z\,(P(z,x) \wedge P(z,y))$	Overlap

Mereologies

- Partial order can be many things!
  - weights, numbers, instants, preferences…
- Further specifications and *varieties* of mereologies
  - Supplementation, Extensionality (not linearity)
  - Sums, products, complements
  - General fusion
  - Atomicity / infinite divisibility
  - Mereotopology, mereogeometry…

Transitivity?

- *This horn is part of Margot the cow, Margot is part of my herd,* but *This horn is not part of my herd*
- Winston, Chaffin, Hermann 1987
  - Not one, but several parthood relations:
    - **component-integral object** (*handle-door, engine-car*)
    - **member-collection** (*tree-forest, cow-herd*)
    - **portion-mass** (*slice-pie*)
    - **stuff-object** (*steel-bike, sugar-bottle of syrup*)
    - **feature-activity** (*paying-shopping*)
    - **place-area** (*oasis-desert*)
  - ➢ Each relation is transitive, intransitivities occur with mixed parthoods
  - This is actually false!

Transitivity?

- Lyons 1977, Cruse 1986
  - *The jacket has a sleeve,*
    The sleeve has a cuff, so
    The jacket has a cuff
  - *The house has a door*,
    The door has a handle, but
    The house does not have a handle
- Also Simons, Johansson, Varzi…
- φ-*Part(x,y)* $\equiv_{df}$ *P(x,y)* $\wedge$ φ*(x,y)*
- What is φ?

Ontological grounds for Parthood variety

- Number
  - Singular entities / collections
  - Also linguistically relevant (plurals, count/mass distinction)
  - ➢ **Member-collection** (tree-forest, cow-herd), NT
  - ➢ **Subcollection-collection** (Benelux-EU) missing from WCH87, T
  - ➢ Mixed transitivity: *(M-coll(x,y)* $\wedge$ *S-coll(y,z))* $\rightarrow$ *M-coll(x,z)*
- Categories + Constitution
  - Fundamental categories ('top-level'):
    physical object, amount of matter, substance, event, time, location
  - Again, linguistic counterpart with the count/mass distinction
  - ➢ **Portion-whole** (slice-pie), T
  - ➢ **Substance-whole** (steel-bike, sugar-bottle of syrup), T
  - ➢ Event parthood? Location parthood??

Missing relations

- **Piece-whole** (*front-car, left part-table*…)
  Internal localization nouns
  ➢ Simplest relation, mereotopology suffices
- **Component-integral whole** / functional part (*handle-door, cuff-sleeve, engine-car, cell-heart, electron-atom*…)
  The main parthood relation

Functional parthood

- Function is crucial
  - The part "plays a role" within the whole
  - The whole (and the part) is / are "integral entities"
- Which notion of function?
  - Functional parthood equally applies to artefacts, organisms, inanimate natural entities
  - Functional parthood equally applies to flawed or broken artefacts and organisms
- Function is a very complex matter. No off-the-shelf solution.

Function and types

- Normativity
  - need to refer to some "ideal entity", either a prototype or a universal
- Parthood expressions are sensitive to descriptions
  - *La tête du lit / ??la tête du meuble*
  - *The house has a door, the door has a door handle, and the house has a door handle.*

➢ Functional parthood refers to (lexical) types

The idea: functional dependence

- The cuff is part of the sleeve
  All cuffs "functioning-as-a-cuff" require some related sleeve "functioning-as-a-sleeve"
- The engine is part of the car
  All engines "functioning-as-a-engine" require some related machine "functioning-as-a-machine", for instance, a car "functioning-as-a-car"
- The wall is part of the house
  All entities "functioning-as-a-house" require some related entity "functioning-as-a-wall"

Type reification

- Sorted modal first-order logic
  - Particulars: *x, y, z*
  - Lexical types: *X, Y, Z*
    concepts associated to a public definition
- Classification
  CF(x, X, t)
  x exists at time *t* and satisfies at time *t* all the conditions required by the definition of *X* for it to be a *X*.

Dependence

- Specific dependence
  $D(x,y) \equiv \Box\forall t(E(x,t) \rightarrow E(y,t)) \wedge \Diamond\exists t\, E(x,t) \wedge \neg\Box\forall t\, E(y,t)$
  the existence of *x* implies the existence of *y*
- Generic dependence
  $GD(X,Y) \equiv \Box\forall x,t\,(CF(x,X,t) \rightarrow \exists y\, CF(y,Y,t)) \wedge \Diamond\exists x,t\, CF(x,X,t) \wedge \neg\Box\forall t\, \exists y\, CF(y,Y,t)$
  all *X*s imply the existence of some *Y*

Functional dependence

$GFD(X,Y) \equiv$
$\Box\forall x,t\,((CF(x,X,t) \wedge Functioning(x,X,t)) \rightarrow \exists y\,(CF(y,Y,t) \wedge Functioning(y,Y,t))) \wedge \Diamond\exists x,t\,(CF(x,X,t) \wedge Functioning(x,X,t)) \wedge \neg\Box\forall t\, \exists y\,(CF(y,Y,t) \wedge Functioning(y,Y,t))$

all *X*s, when functioning as a *X*, imply the existence of some *Y* that is functioning as a *Y*

Individual functional dependence

- $IFD(x,X,y,Y,t) \equiv GFD(X,Y) \wedge CF(x,X,t) \wedge CF(y,Y,t) \wedge \forall t'\,((P(t',t) \wedge Functioning(x,X,t')) \rightarrow Functioning(y,Y,t'))$
- Indirect individual functional dependence
  $IIFD(x,X,y,Y,t) \equiv CF(y,Y,t) \wedge \exists Z\,(Subclass(Y,Z) \wedge IFD(x,X,y,Z,t))$

Axioms and theorems

- □ is S5
- $(Functioning(x,X,t) \wedge P(t',t)) \rightarrow Functioning(x,X,t')$
- $(Functioning(x,X,t) \wedge Subclass(X,Y)) \rightarrow Functioning(x,Y,t)$

(T1) $(GFD(X,Y) \wedge GFD(Y,Z)) \rightarrow GFD(X,Z)$
(T2) $GFD(X,Y) \wedge Subclass(Y,Z) \wedge \neg\Box\forall t\exists x\,(CF(x,Z,t)) \rightarrow GFD(X,Z)$
(T3) $IFD(x,X,y,Y,t) \rightarrow IIFD(x,X,y,Y,t)$

Defining Functional Parthood

$FP\text{-}D1(x,X,y,Y,t) \equiv PP(x,y,t) \wedge Obj(x) \wedge Obj(y) \wedge IFD(x,X,y,Y,t)$
cuff - sleeve, nucleus - cell, hand - arm

$FP\text{-}D2(x,X,y,Y,t) \equiv PP(x,y,t) \wedge Obj(x) \wedge Obj(y) \wedge IFD(y,Y,x,X,t)$
wall - house, wheel - car, engine - car, hand - arm

$FP\text{-}I1(x,X,y,Y,t) \equiv PP(x,y,t) \wedge Obj(x) \wedge Obj(y) \wedge IIFD(x,X,y,Y,t)$
handle - door, engine - car

$FP\text{-}I2(x,X,y,Y,t) \equiv PP(x,y,t) \wedge Obj(x) \wedge Obj(y) \wedge IIFD(y,Y,x,X,t)$
brick - wall

Defining functional meronymy and holonymy

$FH(X,Y) \equiv \forall x\ \forall t\ (CF(x,X,t) \rightarrow \exists y\ (CF(y,Y,t) \wedge FP\text{-}D1(x,X,y,Y,t)))$
cuff - sleeve, nucleus - cell, hand - arm holonymy

$FM(X,Y) \equiv \forall y\ \forall t\ (CF(y,Y,t) \rightarrow \exists x\ (CF(x,X,t) \wedge FP\text{-}D2(x,X,y,Y,t)))$
wall - house, wheel - car, engine - car, hand - arm meronymy

NB: NO indirect meronymy / holonymy, i.e., no occurrence of
$FH'(X,Y) \equiv \forall x\ \forall t\ (CF(x,X,t) \rightarrow \exists y\ (CF(y,Y,t) \wedge FP\text{-}I1(x,X,y,Y,t)))$
$FM'(X,Y) \equiv \forall y\ \forall t\ (CF(y,Y,t) \rightarrow \exists x\ (CF(x,X,t) \wedge FP\text{-}I2(x,X,y,Y,t)))$
which is not *FH* or *FM*
NO handle - door, engine - car, brick - wall…

Transitivity

Theorems:

(T4) $(FP\text{-}D1(x,X,y,Y,t) \wedge FP\text{-}D1(y,Y,z,Z,t)) \rightarrow FP\text{-}D1(x,X,z,Z,t)$
(T4') $(FH(X,Y) \wedge FH(Y,Z)) \rightarrow FH(X,Z)$
(T5) $(FP\text{-}D2(x,X,y,Y,t) \wedge FP\text{-}D2(y,Y,z,Z,t)) \rightarrow FP\text{-}D2(x,X,z,Z,t)$
(T5') $(FM(X,Y) \wedge FM(Y,Z)) \rightarrow FM(X,Z)$
(T6) $(FP\text{-}D1(x,X,y,Y,t) \wedge FP\text{-}I1(y,Y,z,Z,t)) \rightarrow FP\text{-}I1(x,X,z,Z,t)$
(T7) $(FP\text{-}I2(x,X,y,Y,t) \wedge FP\text{-}D2(y,Y,z,Z,t)) \rightarrow FP\text{-}I2(x,X,z,Z,t)$

Intransitivities

Non-theorems:

(i) $(FP\text{-}I1(x,X,y,Y,t) \wedge FP\text{-}D1(y,Y,z,Z,t)) \rightarrow (FP\text{-}I1(x,X,z,Z,t) \vee FP\text{-}I2(x,X,z,Z,t))$
(ii) $(FP\text{-}D2(x,X,y,Y,t) \wedge FP\text{-}I2(y,Y,z,Z,t)) \rightarrow (FP\text{-}I1(x,X,z,Z,t) \vee FP\text{-}I2(x,X,z,Z,t))$
(iii) $(FP\text{-}D1(x,X,y,Y,t) \wedge FP\text{-}D2(y,Y,z,Z,t)) \rightarrow (FP\text{-}I1(x,X,z,Z,t) \vee FP\text{-}I2(x,X,z,Z,t))$
(iv) $(FP\text{-}D2(x,X,y,Y,t) \wedge FP\text{-}D1(y,Y,z,Z,t)) \rightarrow (FP\text{-}I1(x,X,z,Z,t) \vee FP\text{-}I2(x,X,z,Z,t))$

Puzzles solved

My hand is part of my arm,
My arm is part of my body, so
My hand is part of my body

(T4) $(FP\text{-}D1(x,Hand,y,Arm,t) \wedge FP\text{-}D1(y,Arm,z,Body,t)) \rightarrow FP\text{-}D1(x,Hand,z,Body,t)$

Puzzles solved

The jacket has a sleeve,
The sleeve has a cuff, so
The jacket has a cuff

(T6) $(FP\text{-}D1(x,Cuff,y,Sleeve,t) \wedge FP\text{-}I1(y,Sleeve,z,Jacket,t)) \rightarrow FP\text{-}I1(x,Cuff,z,Jacket,t)$

$Subclass(Jacket, Garment)$

Puzzles solved

This electron is part of this atom,
This atom is part of this molecule, so
This electron is part of this molecule

(T5) $(FP\text{-}D2(x,Electron,y,Atom,t) \wedge FP\text{-}D2(y,Atom,z,Molecule,t)) \rightarrow FP\text{-}D2(x,Electron,z,Molecule,t)$

Puzzles solved

This brick is part of this wall,
This wall is part of the house, so
This brick is part of the house

(T7) (*FP-I2*(*x,Brick,y,Wall,t*) ∧
FP-D2(*y,Wall,z,House,t*)) →
FP-I2(*x,Brick,z,House,t*)

Subclass(*Brick, Building-material*)

Puzzles solved

The house has a door,
The door has a handle, but
The house does not have a handle

(i') (*FP-I1*(*x,Handle,y,Door,t*) ∧
FP-I1(*y,Door,z,House,t*)) →
(*FP-I1*(*x,Handle,z,House,t*) ∨
FP-I2(*x,Handle,z,House,t*))

- *Subclass*(*Door, Objects-that-can-be-moved-or-used-by-hand*)
- *Subclass*(*House, Building-room-cupboard-vehicle*)

(T3) *IFD*(*x,X,y,Y,t*) → *IIFD*(*x,X,y,Y,t*)

Puzzles solved

The nucleus is part of this cell,
This cell is part of the heart, but
The nucleus is not part of the heart

(iii) (*FP-D1*(*x,Nucleus,y,Cell,t*) ∧
FP-D2(*y,Cell,z,Heart,t*)) →
(*FP-I1*(*x,Nucleus,z,Heart,t*) ∨
FP-I2(*x,Nucleus,z,Heart,t*))

Puzzles solved

This cell is part of the heart,
The heart is part of the circulatory system, but
This cell is not part of the circulatory system

(iv) (*FP-D2*(*x,Cell,y,Heart,t*) ∧
FP-D1(*y,Heart,z, CSyst,t*)) →
(*FP-I1*(*x, Cell,z,CSyst,t*) ∨ *FP-I2*(*x, Cell,z,CSyst,t*))

(ii) (*FP-D2*(*x,Cell,y,Heart,t*) ∧
FP-I2(*y,Heart,z,CSyst,t*)) →
(*FP-I1*(*x,Cell,z,CSyst,t*)∨*FP-I2*(*x,Cell,z,CSyst,t*))

- *Subclass*(*Heart, Pump*)

Further linguistic evidence

- Determinative compound nouns
  - Parts determined by wholes
    - *a car engine*, *a door handle, a bag handle*: FP-I1
  - Wholes determined by parts
    - *a brick wall, a motor boat, a sail boat*: FP-I2
  - FP-D1: **an arm hand*, **a sleeve cuff*, ??*a machine engine*
  - FP-D2: **a hand arm*, **a wall house*, **a motor automobile*
- Direct functional dependence implies non-informativeness (Grice's maxim of quantity)

Conclusion

- Some ontology is required to do lexical semantics — as for formal semantics

in addition,

1. Formal ontology tools help doing proper semantics
2. Ontology in isolation from language and cognition is an utopy:
   (lexical? cognitive?) types are needed!

Inheritance

(T8) $(FP\text{-}D1(x,X,y,Y,t) \wedge Subclass(Y,Z) \wedge \neg\Box\forall t\exists z\,(CF(z,Z,t))) \rightarrow FP\text{-}D1(x,X,y,Z,t)$

(T9) $(FP\text{-}D1(x,X,y,Y,t) \wedge Subclass(Z,X)) \rightarrow FP\text{-}D1(x,Z,y,Y,t)$

(T10) $(FP\text{-}D2(x,X,y,Y,t) \wedge Subclass(X,Z) \wedge \neg\Box\forall t\exists z\,(CF(z,Z,t))) \rightarrow FP\text{-}D2(x,Z,y,Y,t)$

(T11) $(FP\text{-}D2(x,X,y,Y,t) \wedge Subclass(Z,Y)) \rightarrow FP\text{-}D2(x,X,y,Z,t)$

(T12) $(FP\text{-}I1(x,X,y,Y,t) \wedge Subclass(Z,X)) \rightarrow FP\text{-}I1(x,Z,y,Y,t)$

(T13) $(FP\text{-}I2(x,X,y,Y,t) \wedge Subclass(Z,Y)) \rightarrow FP\text{-}I2(x,X,y,Z,t)$

Inheritance

But not

(v) $(FP\text{-}D1(x,X,y,Y,t) \wedge Subclass(Z,Y) \wedge \neg\Box\forall t\exists z\,(CF(z,Z,t))) \rightarrow FP\text{-}D1(x,X,y,Z,t)$

(vi) $(FP\text{-}D2(x,X,y,Y,t) \wedge Subclass(Y,Z) \wedge \neg\Box\forall t\exists z\,(CF(z,Z,t))) \rightarrow FP\text{-}D1(x,X,y,Z,t)$

…

Puzzles solved

- *Birds have wings, canaries are birds,*
  so
  canaries have wings (T11')
- *Cuffs are parts of sleeves, short sleeves are sleeves,*
  but
  short sleeves don't have cuffs (v')
- *La tête du lit,*
  but not
  la tête du meuble (vi)