Semantic Theory

Introduction

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Structure of the Course

- Part I: Compositional Semantics
  - Type Theory, Semantics Construction, Scope Ambiguities, Underspecification
- Part II: Discourse Semantics
  - Discourse Representation Theory (DRT), Anaphora and Coreference, Definite Descriptions, Presuppositions
- Part III: Lexical Semantics
  - Event and Frame Semantics, Metaphor and Metonymy, Generative Lexicon

Compositional Semantics: Research Questions

- What is the meaning of a sentence? How can we represent it?
- How can we compute semantic representations for a given sentence?
- How can we deal with (structural) ambiguity?

Sentence Meaning

- To know the meaning of a (declarative) sentence S is to know the conditions under which the sentence is true.
- Meaning of S = truth-conditions of S
  - “Max reads a book” is true iff ...
- The meaning of a sentence can be represented by logical expressions:
  - $\exists x(book(x) \wedge read(max, x))$ is true iff ...

- Note that there are also aspects of meaning “beyond” truth-conditions (e.g., anaphora, implicatures, ...).

Predicate Logic: Syntax

- Non-logical expressions:
  - Individual constants: CON
  - n-place predicate symbols: $PRED^n$ (for all $n \geq 0$)
- Individual variables: VAR
- Terms: TERM = VAR ∪ CON

Predicate Logic: Syntax

- Atomic formulas:
  - $R(t_1, \ldots, t_n)$ for $R \in PRED^n$, $t_1, \ldots, t_n \in TERM$
  - $s = t$ for $s, t \in TERM$
- Well-formed formulae: the smallest set FORM such that
  - all atomic formulas are in FORM
  - if A, B are in FORM, then $\neg A$, $(A \wedge B)$, $(A \vee B)$, $(A \rightarrow B)$, $(A \leftrightarrow B)$ are in FORM
  - If x is an individual variable and A is in FORM, then $\forall xA$ and $\exists xA$ are in FORM

Representing Meaning

(1) *Max is a student*

⇒ student(max)

(2) *Max reads a book*

⇒ ∃x(book(x) ∧ read(max, x))

(3) *Not all students passed the exam*

⇒ ¬∀x(student(x) → pass(x, the-exam))

⇒ ∃y(∀z(exam(z) ↔ z = y) ∧ ¬∀x(student(x) → pass(x, z))

Predicate Logic: Semantics

- Expressions of Predicate Logic are interpreted relative to model structures and variable assignments.
- Model structures: $M = \langle U_M, V_M \rangle$
  - U_M is a non-empty universe (domain of individuals)
  - V_M is an interpretation function assigning individuals ($\in U_M$) to individual constants and n-ary relations over U_M to n-place predicate symbols.
- Assignment function for variables $g: VAR \rightarrow U_M$

Predicate Logic: Semantics

- Interpretation of terms with respect to a model structure M and a variable assignment g:
  - $[\![\alpha]\!]^{M,g} = V_M(\alpha)$, if α is an individual constant
  - $[\![\alpha]\!]^{M,g} = g(\alpha)$, if α is a variable

Predicate Logic: Semantics

- Interpretation of formulas with respect to a model structure M and variable assignment g:

$$[\![R(t_1, \ldots, t_n)]\!]^{M,g} = 1 \quad \text{iff} \quad ([\![t_1]\!]^{M,g}, \ldots, [\![t_n]\!]^{M,g}) \in V_M(R)$$
$$[\![s = t]\!]^{M,g} = 1 \quad \text{iff} \quad [\![s]\!]^{M,g} = [\![t]\!]^{M,g}$$
$$[\![\neg\varphi]\!]^{M,g} = 1 \quad \text{iff} \quad [\![\varphi]\!]^{M,g} = 0$$
$$[\![\varphi \wedge \psi]\!]^{M,g} = 1 \quad \text{iff} \quad [\![\varphi]\!]^{M,g} = 1 \text{ and } [\![\psi]\!]^{M,g} = 1$$
$$[\![\varphi \vee \psi]\!]^{M,g} = 1 \quad \text{iff} \quad [\![\varphi]\!]^{M,g} = 1 \text{ or } [\![\psi]\!]^{M,g} = 1$$
$$[\![\varphi \rightarrow \psi]\!]^{M,g} = 1 \quad \text{iff} \quad [\![\varphi]\!]^{M,g} = 0 \text{ or } [\![\psi]\!]^{M,g} = 1$$
$$[\![\varphi \leftrightarrow \psi]\!]^{M,g} = 1 \quad \text{iff} \quad [\![\varphi]\!]^{M,g} = [\![\psi]\!]^{M,g}$$
$$[\![\exists x\varphi]\!]^{M,g} = 1 \quad \text{iff} \quad \text{there is a } d \in U_M \text{ such that } [\![\varphi]\!]^{M,g[x/d]} = 1$$
$$[\![\forall x\varphi]\!]^{M,g} = 1 \quad \text{iff} \quad \text{for all } d \in U_M, [\![\varphi]\!]^{M,g[x/d]} = 1$$

- g[x/d] is the variable assignment which is identical to g except that it assigns the individual d to variable x.

Predicate Logic: Semantics

- Formula A is true in the model structure M iff $[\![A]\!]^{M,g} = 1$ for every variable assignment g.
- A model structure M satisfies (or: is a model for) a set of formulas Γ iff every formula A ∈ Γ is true in M.
- A set of formulas Γ entails formula A (notation: $\Gamma \vDash A$) iff A is true in every model of Γ.

Entailment

(1) *[At the end of the year,] all companies [have to] file an annual report.*

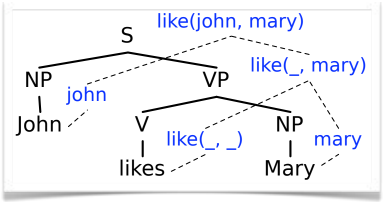
(2) *[At the end of the year,] all solid companies [have to] file an annual report.*

(3) *[At the end of the year,] all companies pay a dividend.*

(4) *[At the end of the year,] all companies pay a cash dividend.*

Computing Meaning

- How can we automatically compute a semantic representation for a given sentence?
- Basic idea: we consider the syntactic structure of a sentence, and recursively “read off” a semantic representation from the syntax tree.



A Challenge for Semantic Composition

(1) *Every student reads a book.*

(2) ∀x(student(x) → ∃y(book(y) ∧ read(x, y)))

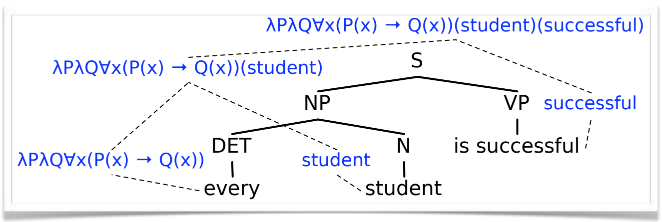
- Solution: Type Theory
  - “every” ⇒ λPλQ∀x(P(x) → Q(x))
  - “a” ⇒ λPλQ(P(x) ∧ Q(x))
  - ...

“Every student is successful”

(1) *Every student is successful*

(2) λPλQ∀x(P(x) → Q(x))(student)(successfull)

(3) ∀x(student(x) → successfull(x))



Another Challenge: Scope Ambiguities

(1) *Every student reads a book*

⇒ ∀x(student(x) → ∃y(book(y) ∧ read(x, y)))

⇒ ∃y(book(y) ∧ ∀x(student(x) → read(x, y)))

(2) *Every student did not pass [the exam]*

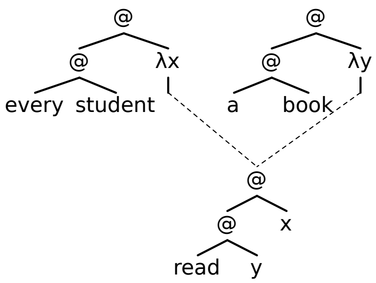
⇒ ∀x(student(x) → ¬pass(x))

⇒ ¬∀x(student(x) → pass(x))

(3) *Pola wants to marry a millionaire*

Underspecification

(1) *Every student reads a book.*



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Discourse Semantics

- How are semantic discourse representations built up from sequences of sentences in text or turns in a dialogue?
- How does sentence meaning interact with context, yielding the intended utterance information?
- How can we infer the relevant information in the respective situation from the utterance information?

Context Dependence

- Deictic expressions point to objects in the physical or visual utterance situation:
  - I, you, here, this, …
- Anaphoric expressions refer to objects in the linguistic context
  - he, she, it, his, her, one (“the one you are holding”)

Context Dependence

- Almost all expressions are dependent on context in one or the other way.
  (1) *Every student must be familiar with the basic properties of first-order logic.*
  (2) *John is always late.*
  (3) *Its hot and sunny everywhere.*
  (4) *Another one, please!*

Definite and Indefinite Noun Phrases

- In text and discourse semantics, there is a “collaboration” between indefinite and definite noun phrases.
  - *A professor owns a book. He likes the book.*
- Indefinite noun phrases introduce reference objects (“discourse referents”). Anaphora and definite noun phrases can be used to refer to them anaphorically.
- Discourse representation theory (DRT) models this process.

Discourse Representation Theory

(1) *A professor owns a book.*

x y
professor(x) book(y) own(x, y)

Discourse Representation Theory

- *A professor owns a book. He likes the book.*

x y z u
professor(x) book(y) own(x, y) z = x u = y like(z, u)

Discourse Representation Theory

(1) *If a professor owns a book, he reads it.*

x y	⇒	z w
professor(x) book(y) own(x, y)		z = x w = y read(z, w)

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Lexical Semantics

- What is word meaning?
- How can it be appropriately represented and organised?
- How can it be acquired in an efficient way?

Major Word-Semantic Categories

- Function words:
  - Connectives and quantifiers,
  - auxiliary and modal verbs,
  - Temporal and modal adverbials, ...
- Content words
  - Common nouns,
  - Full verbs,
  - Adjectives
- Other
  - Named Entities (Persons, institutions, geographic entities, ...)
  - Numbers, ...

Entailment

(1) *Insurgents in Iraq killed five U.S. soldiers [...]*

(2) *Insurgents have attacked U.S. troops [...]*

(3) *Greek coastguard officials [...] have found a body on a boad [...]*

(4) *Coastguard officials have found a dead man.*

Word Senses of "body" (WordNet)

- S: (n) **body**, organic structure, physical structure (the entire structure of an organism (an animal, plant, or human being)) "*he felt as if his whole body were on fire*"
- S: (n) **body** (a group of persons associated by some common tie or occupation and regarded as an entity) "*the whole body filed out of the auditorium*"; "*the student body*"; "*administrative body*"
- S: (n) **body**, dead body (a natural object consisting of a dead animal or person) "*they found the body in the lake*"
- S: (n) **body** (an individual 3-dimensional object that has mass and that is distinguishable from other objects) "*heavenly body*"
- S: (n) torso, trunk, **body** (the body excluding the head and neck and limbs) "*they moved their arms and legs and bodies*"
- [...]

Challenges in Lexical Semantics

- The multiplicity of senses: Lexical ambiguity
- The diversity of meaning information (in a given sense)
- The size of the lexicon

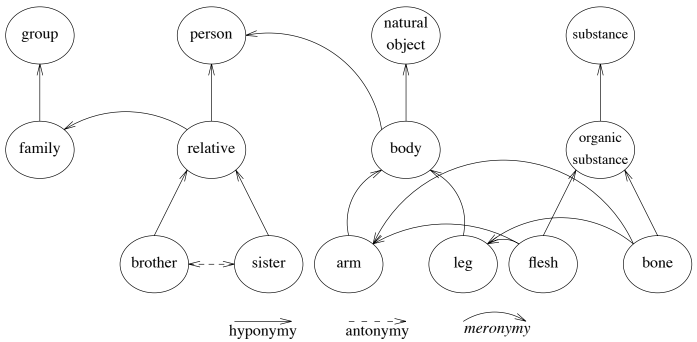
The Word-Meaning Relationship

- No one-to-one relation between
  - phonological / orthographic words and
  - senses / word meanings / concepts.
- One sense / concept can be encoded in different phonological words: Synonymy
- One phonological word can be associated with several senses: Lexical ambiguity
  - Homonymy (unrelated senses)
  - Polysemy (semantically related concepts)

Semantic Relations

- Hyponymy / Hypernymy (the "IS-A" relation):
  - dolphin – mammal
- Synonymy:
  - case – bag
- Meronymy/Holonymy
  - Part / Whole : branch – tree
  - Member / Group: tree – forest
  - Matter / Object: wood – tree
- Contrast
  - Complementarity: boy – girl
  - Antonymy: long – short

Semantic Relations



(WordNet)

WordNet

- WordNet is a large lexical-semantic resource, organised as a semantic network.
- Concepts / readings in WordNet are represented by so-called "synsets" – sets of synonymous words. These "synsets" are the nodes of the semantic network.
- English WordNet: about 150.000 lexical items, 120.000 synsets, 200.000 word-sense pairs
- Versions of WordNet for available for about 30 languages

Verb Alternations

(1) *The window broke*

(2) *A rock broke the window*

(3) *John broke the window with a rock*

- (3) $\models$ (2) $\models$ (1)
- $break_3(x,y,z) \models break_2(z,y) \models break_1(y)$

Thematic Roles

(1) *[The window]$_{pat}$ broke*

(2) *[A rock]$_{inst}$ broke [the window]$_{pat}$*

(3) *[John]$_{ag}$ broke [the window]$_{pat}$ [with a rock]$_{inst}$*

- Some thematic roles:
  - Agent
  - Theme / Patient / Object
  - Recipient
  - Instrument
  - …

A More Complex Example

- Which Airlines buy planes from Airbus?

- Airbus sells five A380 superjumbo planes to China Southern for 220 million Euro
- China Southern buys five A380 superjumbo planes from Airbus for 220 million Euro
- Airbus arranged with China Southern for the sale of five A380 superjumbo planes at a price of 220 million Euro
- Five A380 superjumbo planes will go for 220 million Euro to China Southern

Thematic Roles and Frames

- COMMERCIAL TRANSACTION
  - SELLER: Airbus
  - BUYER: China Southern
  - GOODS: five A380 superjumbo planes
  - PRICE: 220 million Euro

Berkeley FrameNet

- Frames: an inventory of conceptual structures modelling a prototypical situation like COMMERCIAL TRANSACTION
- Semantic roles are locally valid only and accordingly called “Frame Elements” (FE):
  - Frame elements of the COMMERCIAL TRANSACTION frame: BUYER, SELLER, GOODS, PRICE, ...
- A set of “target words” associated with each frame: e.g., for COMMERCIAL TRANSACTION:
  - buy, sell, pay, spend, cost, charge,
  - price, change, debt, credit, merchant, broker, shop
  - tip, fee, honorarium, tuition

Organisational Issues

- Books
- Website
- Exercises
- Exercise vs. lecture sessions
- Final Exam