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LST Prep Course: Semantics

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Units of Language – Subfields of Linguistics

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	Grammar	Semantics	Pragmatics
Sound	Phonetics/ Phonology	---	---
Word	Morphology	Lexical Semantics	---
Sentence	Syntax	Compositio nal Semantics	Pragmatics
Text& Discourse	Text & Discourse Grammar	Discourse Semantics	Pragmatics
	Structure	Meaning	Use

Research Questions in Semantics

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1. What is word meaning? How can it be appropriately represented and organised? How can it be acquired in an efficient way?
2. How can sentence meaning be appropriately represented? How can it be built up/ composed from word meanings and syntactic information?
3. How are semantic discourse representations built up from sequences of sentences in text or turns in a dialogue?
4. How does sentence meaning interact with context, yielding the intended utterance information?
5. How can we infer the relevant information in the respective situation from the utterance information?

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The Representation of Sentence Meaning

Representation of Sentence Meaning

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Predicate Logic (1)

- *John walks* → walk (john)
- *John likes Mary* → like(john, mary)
- *John is Bill's brother* → brother-of(john, bill)
- *John gives Mary the book* →
  give (john, mary, the-book)
- *Saarbrücken is closer to France than Hamburg is to Denmark* → closer-to (sb, france, hh', denmark')

Representation of Sentence Meaning

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Predicate Logic (2)

- *The big red block is in the box*

  → $big(b) \wedge red(b) \wedge block(b) \wedge box(x) \wedge in(b,x)$

Representation of Sentence Meaning

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Predicate Logic (3)

Dolphins are mammals, not fish.

$\forall d\ (dolphin(d) \rightarrow mammal(d) \wedge \neg fish(d))$

Dolphins live in pods.

$\forall d\ (dolphin(d) \rightarrow \exists x\ (pod(p) \wedge live\text{-}in\ (d,p))$

Dolphins give birth to one baby at a time.

$\forall d\ (dolphin(d) \rightarrow \forall x\ \forall y\ \forall t\ (give\text{-}birth\text{-}to\ (d,x,t) \wedge give\text{-}birth\text{-}to\ (d,y,t) \rightarrow x=y)$

Syntax of FOL [1]

- Non-logical expressions:
  - Individual constants: IC
  - n-place predicate symbols: RC^n ($n \geq 0$)
- Individual variables: IV
- Terms: $T = IV \cup IC$
- Atomic formulas:
  - $R(t_1,...,t_n)$ for $R \in RC^n$, if $t_1, ..., t_n \in T$
  - $s=t$ for $s, t \in T$

Syntax of FOL [2]

- FOL formulas: The smallest set *For* such that:
  - All atomic formulas are in *For*
  - If A, B are in *For*, then so are $\neg$ A, $(A \wedge B)$, $(A \vee B)$, $(A \rightarrow B)$,$(A \leftrightarrow B)$
  - If x is an individual variable and A is in *For*, then $\forall xA$ and $\exists xA$ are in *For*.

Semantics of FOL [1]

- Model structures for FOL: M = <U, V>
  - U (or U_M) is a non-empty universe (domain of individuals)
  - V (or V_M) is an interpretation function, which assigns individuals ($\in U_M$) to individual constants and n-ary relations between individuals ($\in U_M^n$) to n-place predicate symbols.
- Assignment function for variables g: IV → U_M

Semantics of FOL [2]

- 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

Semantics of FOL [3]

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

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

- $g[x/a]$ is the variable assignment which is identical with g except that it assigns the individual *a* to the variable x.

Semantics of FOL [4]

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

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Semantics and Inference

Research Questions in Semantics

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Entailment and Deduction

- Calculi can be implemented to obtain:
  - theorem provers: check entailment, validity, and unsatisfiability
  - model builders: check satisfiability, compute models
  - model checkers: determine whether model satisfies formula

Inference in natural language understanding

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Examples:

- *Have you ever been in France?*
- *I was in Paris last year.*

- *Does Bill like lamb chops?*
- *Bill is a vegetarian.*

- *Which Airlines buy planes from Airbus?*
- *Airbus sells 5 A 380 planes to China Southern.*

Logic as a framework for NL semantics

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- (First-order) Logic supports precise, consistent and controlled meaning representation via truth-conditional interpretation.
- (First-order) Logic provides deduction systems to model inference processes, controlled through a formal entailment concept.
- Reading: L.T.F. Gamut, Logic, Language, and Meaning. Volume1:Introduction to Logic. University of Chicago Press 1991

Research Questions in Semantics

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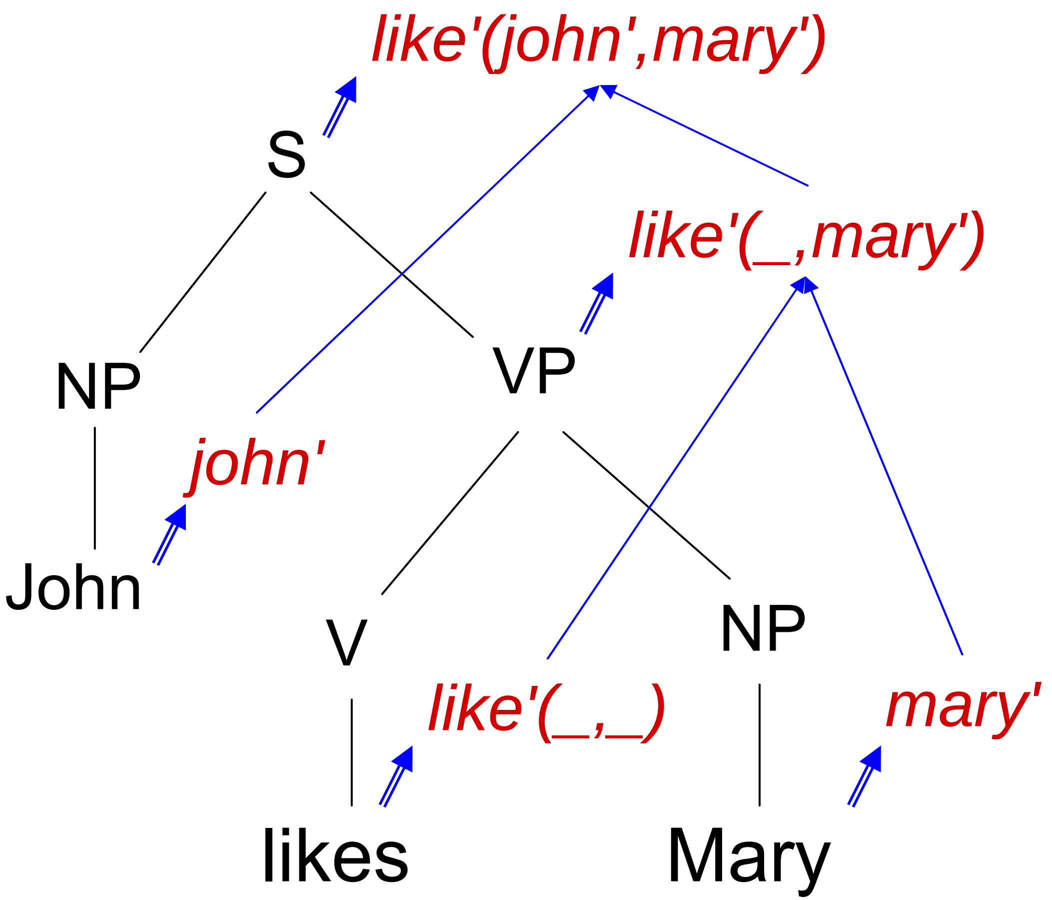
The Construction of Sentence Meaning [1]

Basic Semantic Composition



A Challenge for Semantic Composition

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Every student presented a paper

$$\forall d\ (student(d) \rightarrow \exists p\ (paper(p) \wedge present(d,p)))$$

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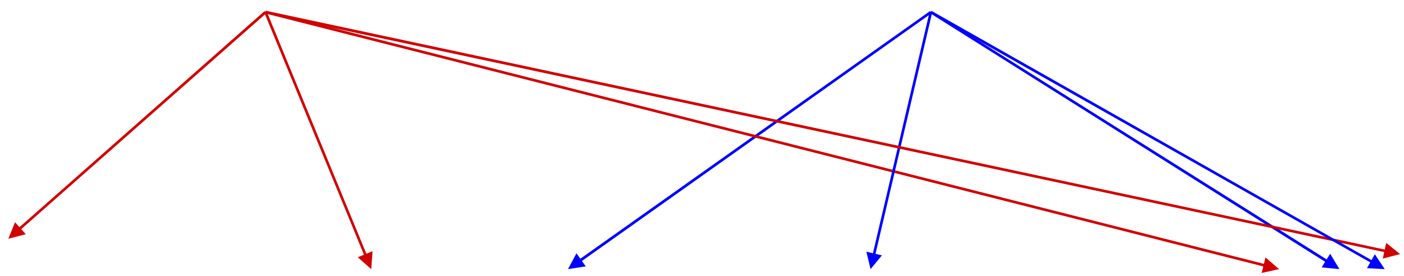

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Word Meaning

Dolphins in First-order Logic

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Dolphins are mammals, not fish.

$\forall d\ (dolphin'(d) \rightarrow mammal'(d) \wedge \neg fish'(d))$

Dolphins live-in pods.

$\forall d\ (dolphin'(d) \rightarrow \exists x\ (pod'(p) \wedge live\text{-}in'(d,p))$

Dolphins give birth to one baby at a time.

$\forall d\ (dolphin'(d) \rightarrow$

$\forall x\ \forall y\ \forall t\ (give\text{-}birth\text{-}to'\ (d,x,t) \wedge give\text{-}birth\text{-}to'\ (d,y,t) \rightarrow x=y)$

Lexical semantics

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Dolphins are mammals, not fish. They are warm blooded like man, and give birth to one baby called a calf at a time. At birth a bottlenose dolphin calf is about 90-130 cms long and will grow to approx. 4 metres, living up to 40 years. They are highly sociable animals, living in pods which are fairly fluid, with dolphins from other pods interacting with each other from time to time.

Challenges in lexical semantics [1]: Size of the lexicon

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- Provision of lexical-semantic information is highly labor- and cost-intensive because the lexicon is
  - very large, actually
  - undelimitable
  - heterogeneuos
  - subject to extreme application-dependent variation

Challenges in lexical semantics [2]

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- Single words can be multiply ambiguous, in particular in central areas of the lexicon.
- There is no clear boundary for the set of readings of a lexical item, because of meaning extensions and figurative uses (metaphor, metonymy):
  - *to like Shakespeare, to eat rabbit, to wear rabbit, to grasp an idea*

Dolphins again

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Dolphins again

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Challenges in lexical semantics [3]

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- The concepts corresponding to single readings of a word are typically multi-layered, consisting of heterogeneous kinds of information:
  - "Propositional" layer
  - Layer of visual (or other sensory) prototypes
  - Stereotypical information
- No sharp boundary between word meaning and extra-linguistic knowledge.

Semantic Relations

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- Thesauri provide implicit information about the basic semantic relation of
  - Hyponymy/Hypernymy (the "ISA relation", e.g., dolphin – mammal)
- There are a number of additional important semantic relations:
  - Synonymy : case – bag
  - Meronymy/Holonymy
    - Part – Whole : branch – tree
    - Member – Group: tree – forest
    - Matter – Object: wood – tree
  - Contrast:
    - Complementarity: boy – girl
    - Antonymy: long – short

WordNet

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- WordNet is a large lexical-semantic resource, organised as a semantic network.
- Concepts/readings in WordNet are represented by „synsets“: Sets of synonymous words. „Synsets“ form the nodes of the semantic network.

An example: *case*

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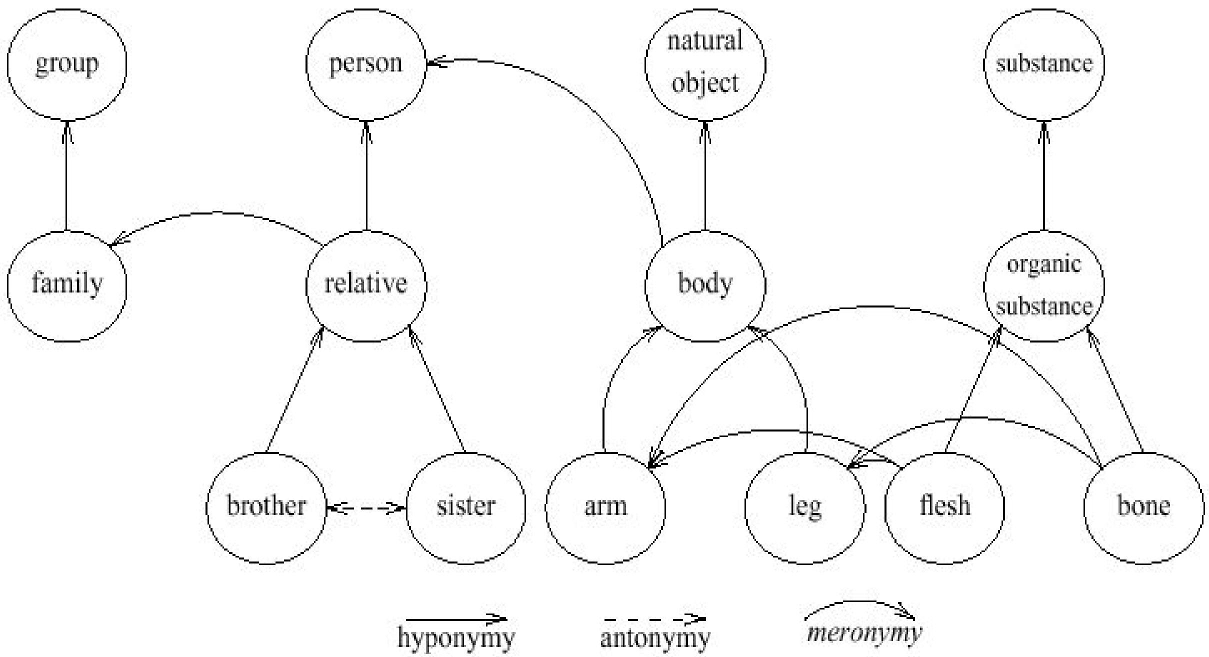
- {*case*, *carton*}
- {*case*, *bag*, *suitcase*}
- {*case*, *pillowcase*, *slip*}
- {*case*, *cabinet*, *console*}
- {*case*, *casing* (the enclosing frame around a door or window opening)}
- {*case* (a small portable metal container)}

An example

Figure 2. Network representation of three semantic relations among an illustrative variety of lexical concepts



WordNet

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- English WordNet: about 150.000 lexical items
  - Web Interface: http://wordnet.princeton.edu/perl/webwn
  - General Info: http://wordnet.princeton.edu/
- "GermaNet": a German WordNet version with about 90.000 lexical items
- Versions of WordNet for available for about 30 languages
- WordNet consists of different, basically unrelated data-bases for common nouns, verbs, adjectives (and adverbs)
- ´The respective hierarchies have a number of "unique beginners" each.

Thematic Roles and Frames

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- *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

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Discourse Semantics

Semantic context dependence

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- Deictic expressions point to objects in the physical / 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")*

Semantic context dependence

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- *Almost all expressions are dependent on context in one or the other way.*
  - *Every student must be familiar with the basic properties of FOL*
  - *John always is late.*
  - *Its hot and sunny everywhere.*
  - *Dolphins from different pods interact from time to time.*
  - *Another one, please!*

Definite and indefinite NPs

- In text and discourse semantics, there is a collaboration between definite and indefinite noun phrases.

  A professor owns a book. He likes the book.

- Indefinite noun phrases introduce reference objects ("discourse referents"). Definite noun phrases refer anaphorically to them.
- Discourse representation theory (DRT) models this process.

An example DRS

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

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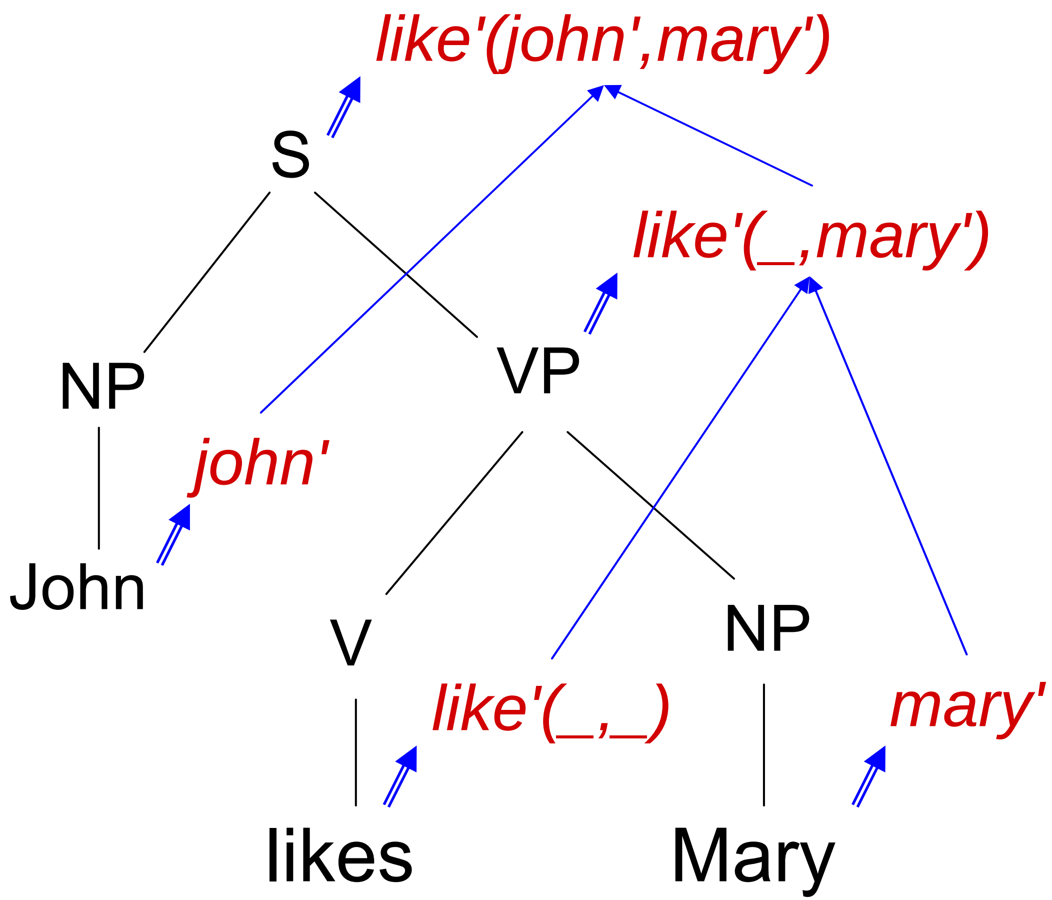
The Construction of Sentence Meaning [2]

Basic Semantic Composition



A Challenge for Semantic Composition

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$$\forall d\ (student(d) \rightarrow \exists p\ (paper(p) \wedge present(d,p)))$$

Do we need more than FOL?

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(This is) a big red block

big(b) ∧ red(b) ∧ block(b)

John is a blond criminal

criminal(j) ∧ blond(j)

John is good piano player

piano-player(j) ∧ good(j)?

John is an alleged criminal

criminal(j) ∧ alleged(j) ??

Do we need more than FOL?

Yesterday, it rained.

It rains occasionally.

Bill is blond. Blond is a hair colour.

$\not\models$ *Bill is a hair colour*

Types

- The set of basic types is {e, t} :
  - e (for entity) is the type of individual terms
  - t (for truth value) is the type of formulas
- All pairs $<\sigma, \tau>$ made up of (basic or complex) types σ, τ are types. $<\sigma, \tau>$ is the type of functions which map arguments of type σ to values of type τ.
- In short: The set of types is the smallest set **T** such that e,t$\in$**T**, and if $\sigma,\tau \in$**T,** then also $<\sigma,\tau> \in$**T.**

Some useful complex types for NL semantics

- Individual: e
- Sentence: t
- One-place predicate constant: <e,t>
- Two-place relation: <e,<e,t>>
- Sentence adverbial: <t,t>
- Attributive adjective: <<e,t>,<e,t>>
- Degree modifier: <<<e,t>,<e,t>>,<<e,t>,<e,t>>>

Second-order predicates

- *Bill is blond. Blond is a hair colour:*
  - Bill is represented as a term of type e.
  - "blond" is represented as a term of type <e,t>.
  - "hair colour" is represented as a term of type <<e,t>,t>.
  - "*Bill is a hair colour"* is not even a well-formed statement.

Type-theoretic syntax [1]

- Vocabulary:
  - Possibly empty, pairwise disjoint sets of non-logical constants: Con_τ for every type τ

Higher-order variables

- *Bill has the same hair colour as John.*

- *Santa Claus has all the attributes of a sadist.*

The inventory of type theory

- Constants and variables of every type
- The usual predicate logic operators

Type-theoretic syntax [2]

- The sets of well-formed expressions WE_τ for every type τ are given by:
  - $Con_\tau \subseteq WE_\tau$ for every type τ
  - If $\alpha \in WE_{<\sigma, \tau>}$, $\beta \in WE_\sigma$, then $\alpha(\beta) \in WE_\tau$.
  - If A, B are in WE_t, then so are $\neg$ A, $(A \wedge B)$, $(A \vee B)$, $(A \rightarrow B)$, $(A \leftrightarrow B)$
  - If A is in WE_t, then so are $\forall v A$ and $\exists v A$, where v is a variable of arbitrary type.
  - If α, β are well-formed expressions of the same type, then $\alpha = \beta \in WE_t$.

Building well-formed expressions

Bill drives fast.

drive: <e,t>   fast: <<e,t>,<e,t>>

Bill: e   fast(drive): <e,t>

fast(drive)(bill): t

Mary works in Saarbrücken

mary: e   work: <e,t>   in: <e,<t,t>>   sb: e

work(mary): t   in(sb): <t,t>

in(sb)(work(mary)): t

Type-theoretic Semantics

- The semantics of type theory is completely parallel to its syntax:
  - Type-e-expressions denote entities.
  - Type-t-expressions denote truth values
  - Expression of type $<\sigma,\tau>$ denote functions from denotations of type σ to denotations of type τ.

Frege's Principle

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... or the Principle of Compositionality:

- The meaning of a complex expression is uniquely determined by the meanings of its sub-expressions and its syntactic structure.

Semantics construction

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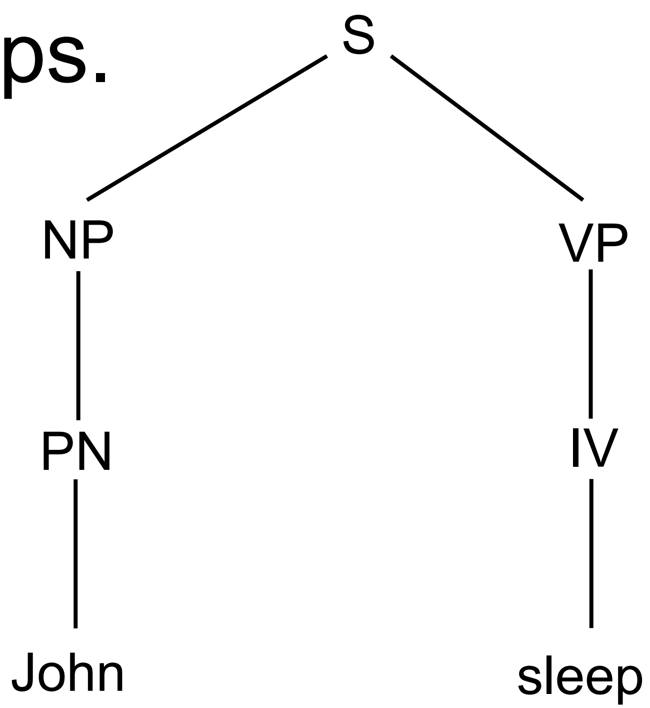
- John sleeps.



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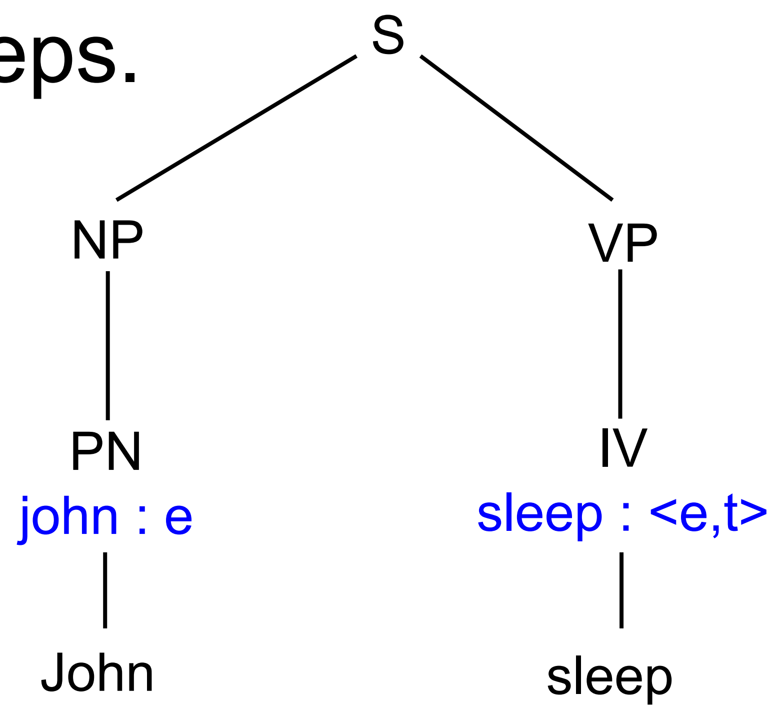

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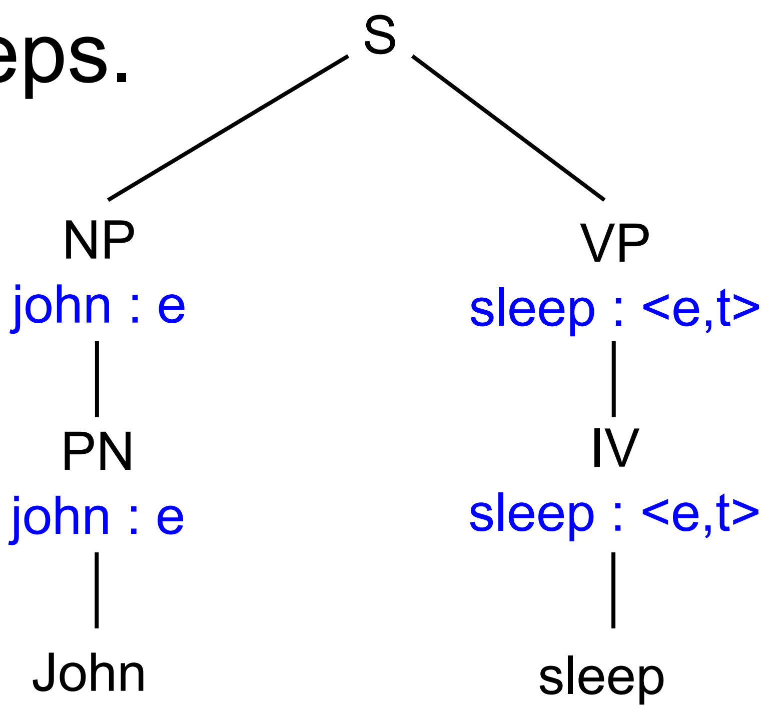

Semantics construction

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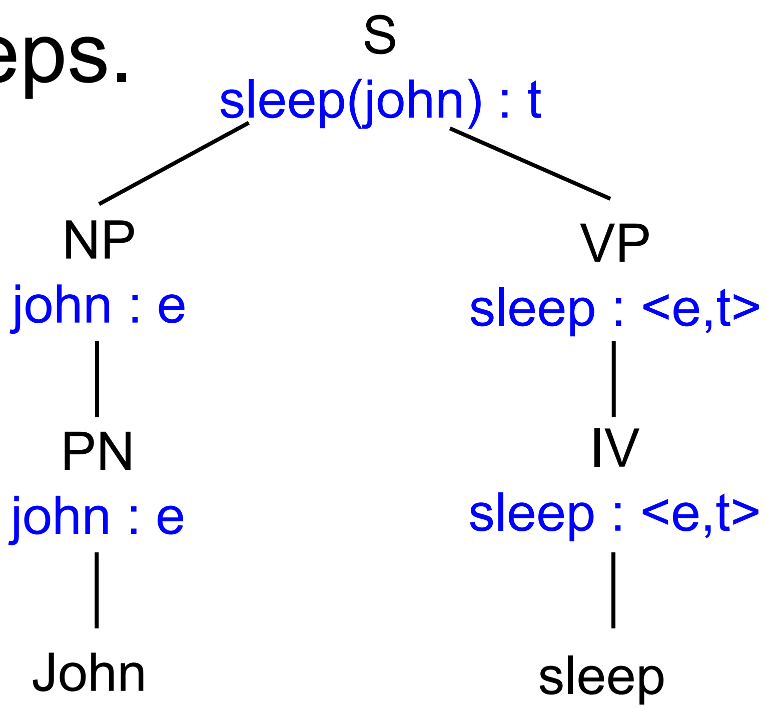

Semantics construction

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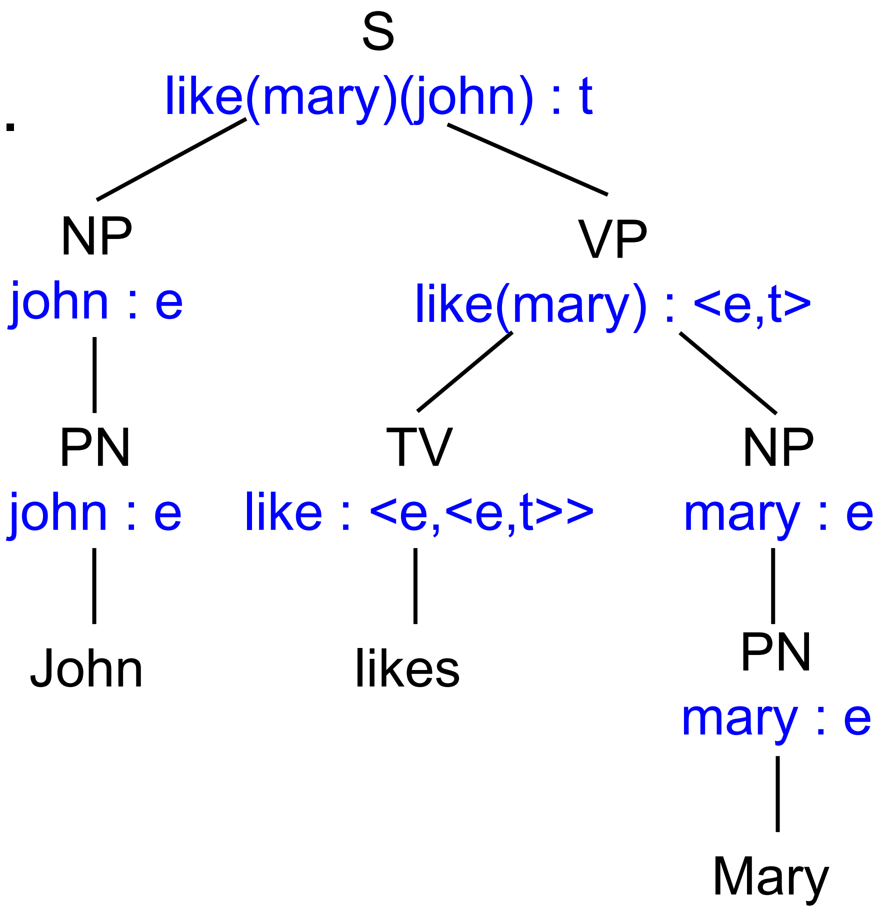
- John likes Mary.



The composition problem again

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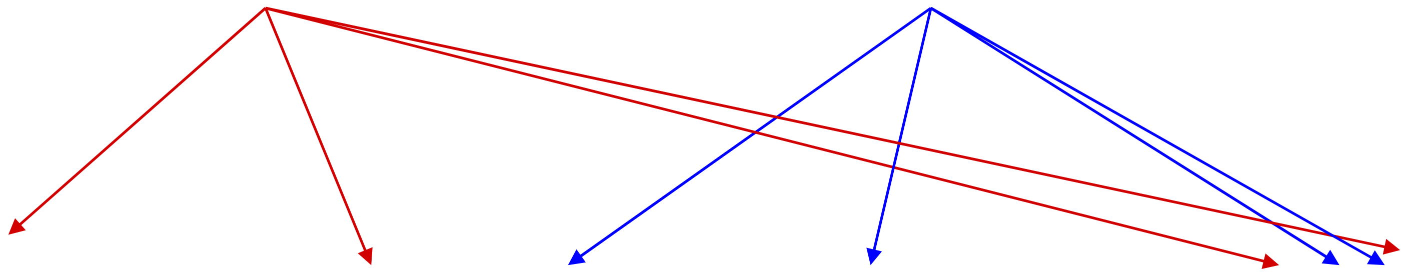
Every student presented a paper



$\forall d\ (student(d) \rightarrow \exists p\ (paper(p) \wedge present(d,p)))$

Another coverage problem

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John drives and drinks

Driving and drinking is dangerous

Example

drive: <e,t>   x:e   drink: <e,t>   x:e

drive(x): t   drink(x): t

drive(x)$\wedge$drink(x): t

λx[drive(x)$\wedge$drink(x)]: <e,t>

Example

John drives and drinks.

drive: <e,t> x:e   drink: <e,t> x:e

drive(x): t   drink(x): t

drive(x)∧drink(x): t

john : e   λx[drive(x)∧drink(x)]: <e,t>

(λx[drive(x)∧drink(x)])(john) : t

β-Reduction

- β-conversion:

  $\lambda v\alpha(\beta) \Leftrightarrow {}^{[\beta/v]}\alpha$,

  if all free variables in β are free for *v* in α.

Example

John drives and drinks.

$\text{drive}: \langle e,t \rangle \quad x:e \qquad \text{drink}: \langle e,t \rangle \quad x:e$

$\text{drive}(x): t \qquad \text{drink}(x): t$

$\text{drive}(x) \wedge \text{drink}(x): t$

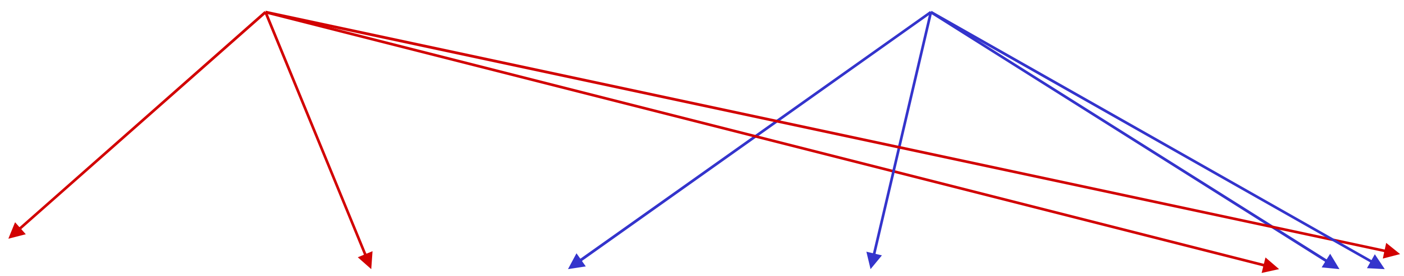
$\text{john} : e \qquad \lambda x[\text{drive}(x) \wedge \text{drink}(x)]: \langle e,t \rangle$

$(\lambda x[\text{drive}(x) \wedge \text{drink}(x)])(\text{john}) : t$

$\Rightarrow_\beta \text{drive}(\text{john}) \wedge \text{drink}(\text{john}) : t$

The composition problem again

Every student presented a paper



$$\forall d\ (\mathrm{student}(d) \rightarrow \exists p\ (\mathrm{paper}(p) \wedge \mathrm{present}(d,p)))$$

Towards a unified semantics of NPs

What's the semantic representation of a noun phrase?

John works.

john: e   work: <e,t>

work(john): t

Every student works.

every-student: e   work: <e,t>

every-student(work): t

This does not work !!!

Towards a unified semantics of NPs

So we try it the other way round:

Every student works.

every-student: <<e,t>,t>   work: <e,t>

every-student(work): t

'Every student' is a complex second-order predicate that is true of a first-order predicate, if all students are in the denotation of that predicate.

Quantified NPs as λ-expressions

- This semantic information can be straightforwardly encoded as a lambda term:

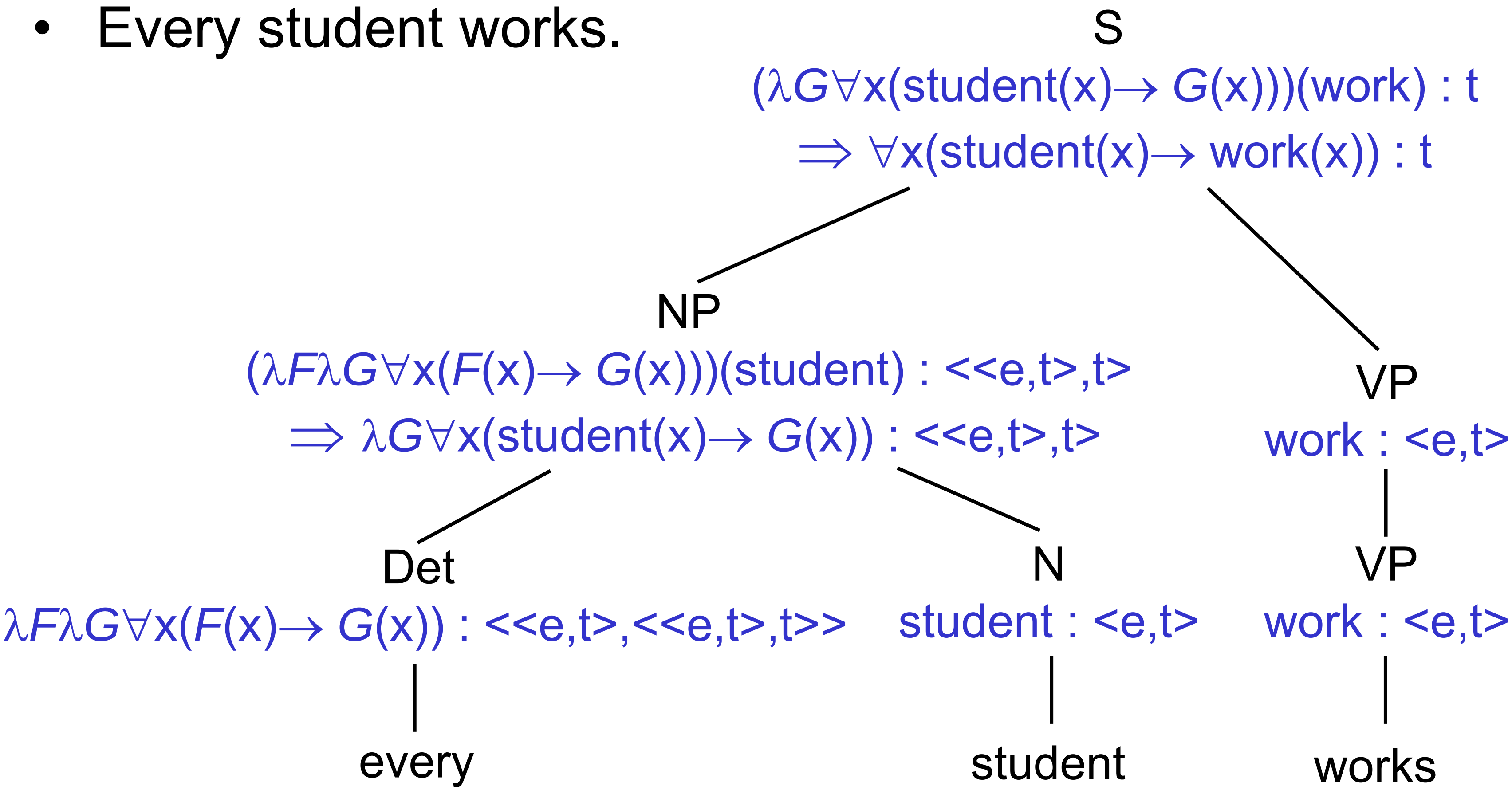
  $\lambda G\ \forall x(\text{student}(x) \rightarrow G(x))$

- Accordingly, the determiner *every* can be represented as:

  $\lambda F \lambda G \forall x(F(x) \rightarrow G(x))$

Semantics construction

- Every student works.



Recommended Reading

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