Foundations of Language Science and Technology

Semantics

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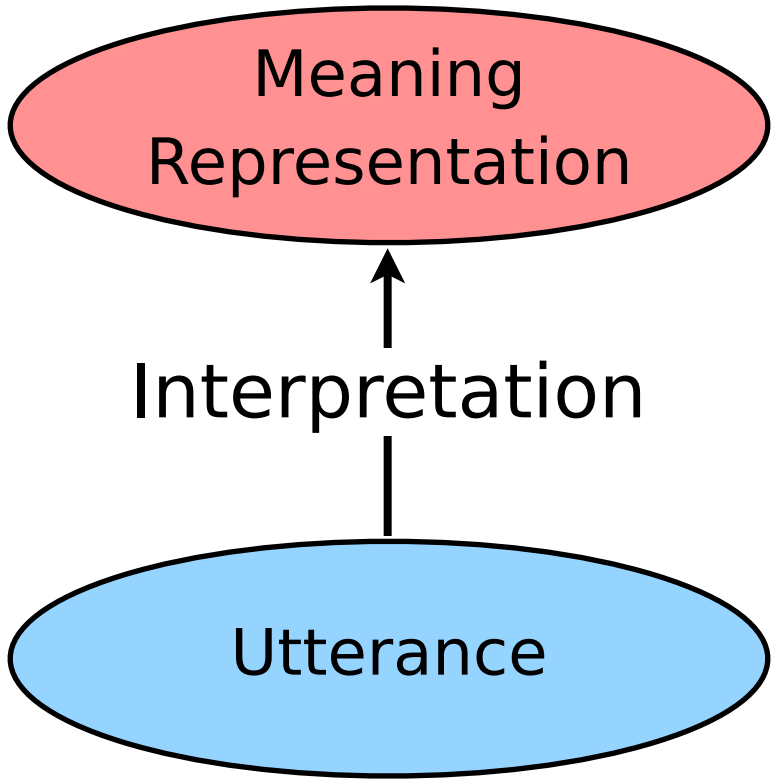
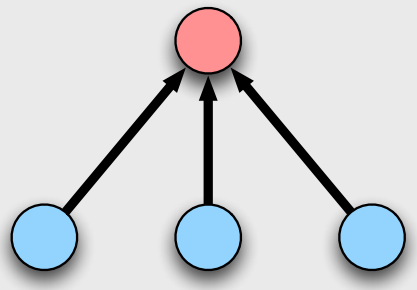
23.01.2008

(based on slides by Manfred Pinkal)

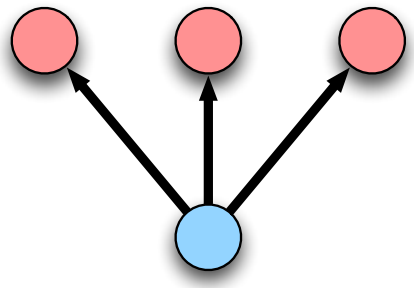
Semantic Interpretation



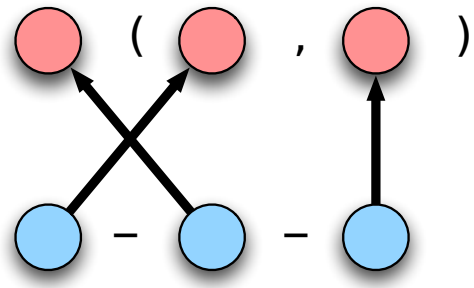
Three Basic Features of Interpretation



Abstraction



Disambiguation



Composition

Three Levels of Semantic Modeling

- Lexical Semantics

  How can we represent word meaning?

- Compositional Semantics (Sentence Semantics)

  How can we represent a sentence‘s meaning? How do we get from word meaning to the meaning of a complex utterance?

- Discourse Semantics (Text, Dialogue)

  How does the meaning of utterances interact with context?

Compositional Semantics

- How can we represent a sentence‘s meaning? How do we get from word meaning to the meaning of a complex utterance?
- Basic assumption: The meaning of a (declarative) sentence are the truth-conditions of the sentence.

Predicate Logic

- *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 paris than Munich is to Vienna*

  ⇒ closer-to‘(sb, paris, m, wien)

Talking about Dolphins

Talking about Dolphins

- *Dolphins are mammals, not fish.*
  - ∀x(dolphin‘(x) ⇒ mammal‘(x) ∧ ¬fish‘(x))
- *Dolphins live in pods.*
  - ∀x(dolphin‘(x) ⇒ ∃y(pod‘(y) ∧ live-in‘(x,y))
- *Dolphins give birth to one baby at a time.*
  - ∀x(dolphin(x) ⇒
    ∀y∀z∀t(give-birth-to‘(x,y,t) ∧ give-birth-to (x,z,t) ⇒ y=z)

Predicate Logic: Syntax [1/2]

- Non-logical expressions:
  - Individual constants: CON
  - n-place predicate symbols: REL^n ($n \geq 0$)
- Individual variables: VAR
- Terms: TERM = VAR ∪ CON
- Atomic formulas:
  - $R(t_1, \ldots, t_n)$ for $R \in REL^n$, $t_1, \ldots, t_n \in TERM$
  - $s = t$ for $s, t \in TERM$

Predicate Logic: Syntax [2/2]

- The set of well-formed formulae (WFF) is the smallest set FORM such that
  - all atomic formulas are in FORM
  - if A, B are in FORM, then ¬A, (A∧B), (A∨B), (A→B), (A↔B) are in FORM.
  - If x is an individual variable and A is in FORM, then ∀xA and ∃xA are in FORM.

Predicate Logic: Semantics [1/4]

- Model structures $M = \langle U, V \rangle$
  - 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: VAR $\rightarrow U_M$

Predicate Logic: Semantics [2/4]

- 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 [3/4]

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

$$[\![R(t_1, \ldots, t_n)]\!]^{M,g} = 1 \text{ iff } ([\![t_1]\!]^{M,g}, \ldots, [\![t_n]\!]^{M,g}) \in V_M(R)$$

$$[\![s = t]\!]^{M,g} = 1 \text{ iff } [\![s]\!]^{M,g} = [\![t]\!]^{M,g}$$

$$[\![\neg\varphi]\!]^{M,g} = 1 \text{ iff } [\![\varphi]\!]^{M,g} = 0$$

$$[\![\varphi \wedge \psi]\!]^{M,g} = 1 \text{ iff } [\![\varphi]\!]^{M,g} = 1 \text{ and } [\![\psi]\!]^{M,g} = 1$$

$$[\![\varphi \rightarrow \psi]\!]^{M,g} = 1 \text{ iff } [\![\varphi]\!]^{M,g} = 0 \text{ or } [\![\psi]\!]^{M,g} = 1$$

...

$$[\![\exists x\varphi]\!]^{M,g} = 1 \text{ iff there is a } a \in U_M \text{ such that } [\![\varphi]\!]^{M,g[x/a]} = 1$$

$$[\![\forall x\varphi]\!]^{M,g} = 1 \text{ iff for all } a \in U_M, [\![\varphi]\!]^{M,g[x/a]} = 1$$

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

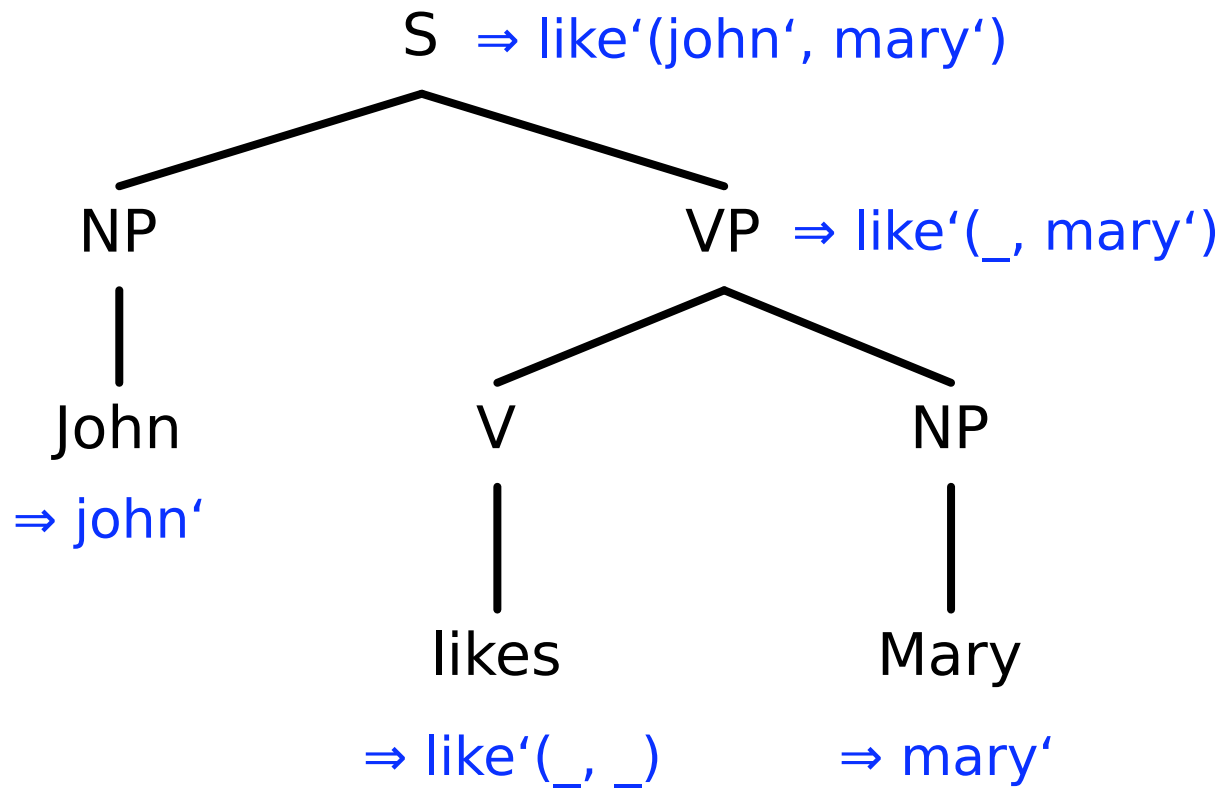
Predicate Logic: Semantics [4/4]

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

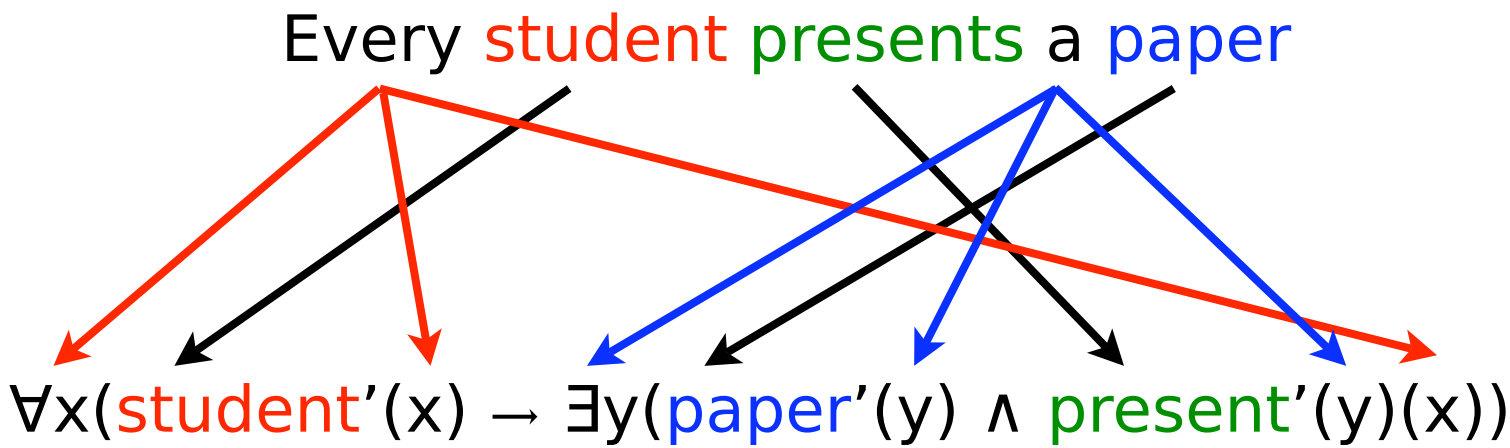
Compositional Semantics

- How can we represent a sentence‘s meaning? How do we get from word meaning to the meaning of a complex utterance?

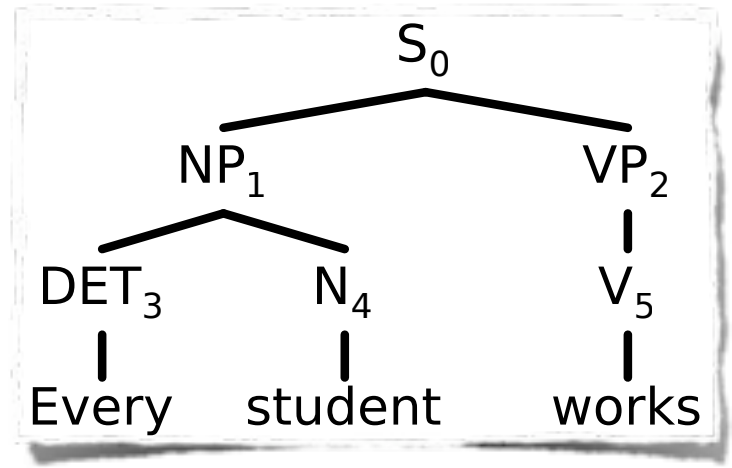
Basic Semantic Composition



A Challenge for Semantic Composition



A Solution: Type Theory



$$
\begin{aligned}
DET_3 &\mapsto \lambda F \lambda G \forall x(F(x) \Rightarrow G(x)) \\
N_4 &\mapsto \text{student}' \\
NP_1 &\mapsto \lambda F \lambda G \forall x(F(x) \Rightarrow G(x))(\text{student}') \\
&\Leftrightarrow_\beta \lambda G \forall x(\text{student}'(x) \Rightarrow G(x)) \\
V_5 &\mapsto \text{work}' \\
VP_2 &\mapsto \text{work}' \\
S_0 &\mapsto \lambda G \forall x(\text{student}'(x) \Rightarrow G(x))(\text{work}') \\
&\Leftrightarrow_\beta \lambda G \forall x(\text{student}'(x) \Rightarrow \text{work}'(x))
\end{aligned}
$$

Logic as a Framework for NL Semantics

- 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.
- Suggested Reading: L.T.F. Gamut, Logic, Language, and Meaning. Volume1: Introduction to Logic. University of Chicago Press 1991

Talking (again) about Dolphins

- 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 bottle-nose dolphin calf is about 90-130 cms long and will grow to approx. 4 meters, 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.

Talking about Dolphins: Predicate Logic

- 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 bottle-nose dolphin calf is about 90-130 cms long and will grow to approx. 4 meters, 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.

What is the meaning of a word?

Encoding Lexical Semantic Information

- Monolingual dictionaries, alphabetically ordered lemmas with enumeration and informal descriptions of readings
  - Oxford English Dictionary
  - Webster‘s
  - Wahrig
  - Duden
  - ...

Encoding Lexical Semantic Information

- A thesaurus presents the lexicon of a language in a hierarchical ordering:
  - Roget‘s Thesaurus (English, since 1805)
  - Dornseiff‘s “Deutscher Wortschatz nach Sachgruppen” (German, 1910)
- Thesauri provide information about the basic semantic relation of Hyponymy/Hypernymy (“IS-A“ relation)

WordNet

- WordNet is a large hierarchical lexical-semantic resource providing meaning representations in terms of relations between concepts in a systematic way.
- Words – Concepts:
  - The same word can express different concepts (ambiguity)
  - The same concept can be expressed by different words (synonymy).
- WordNet: concepts are represented by “synsets:” sets of synonymous words. Synsets are the basic units of WordNet.

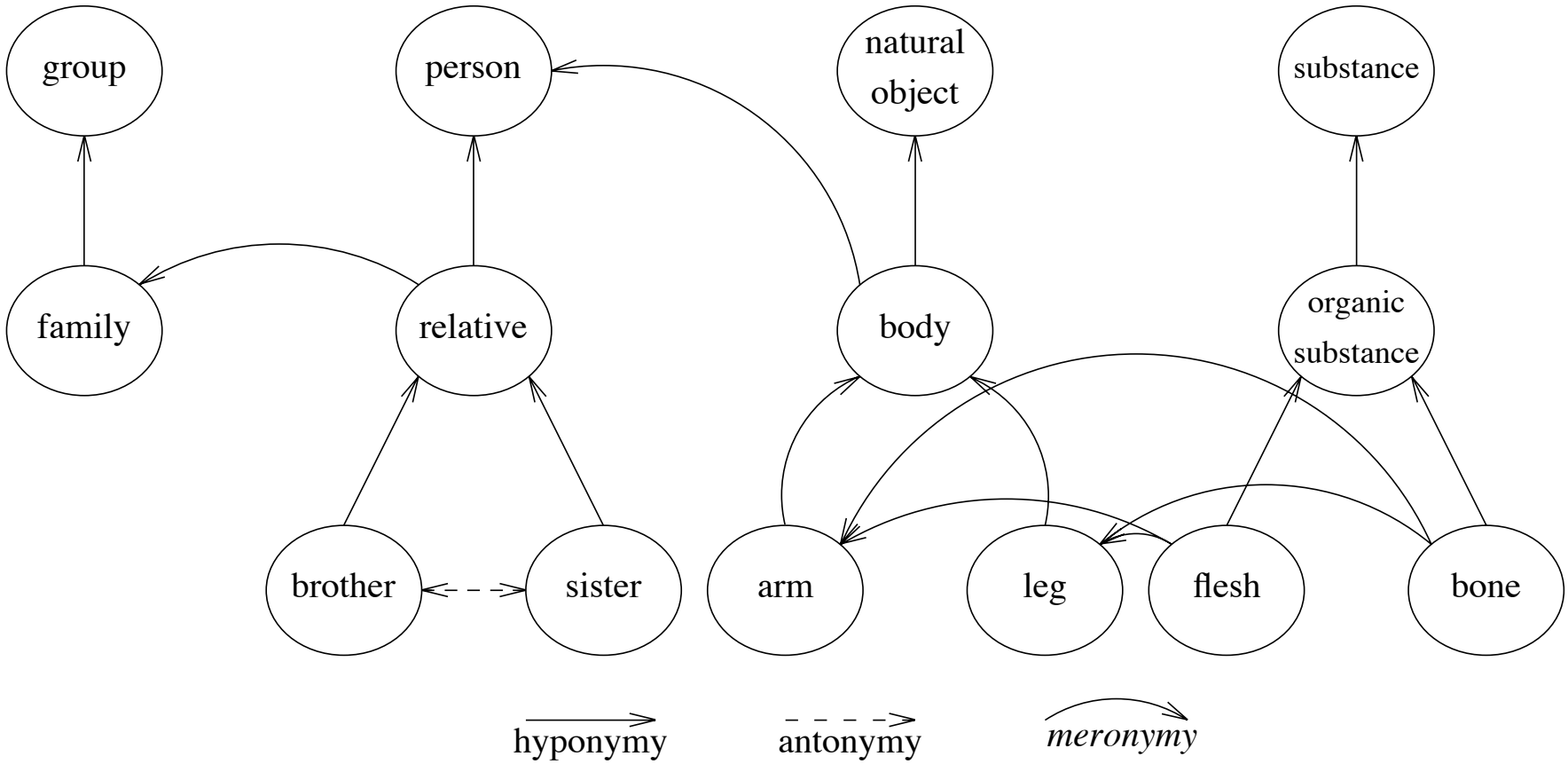
An Example: “case”

- {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)}

Semantic Relations in WordNet

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

An Example



(Miller, 1993)

WordNet – Some more facts

- English WordNet: about 150.000 lexical items
  - Web interface: http://wordnet.princeton.edu/perl/webwn
  - General info: http://wordnet.princeton.edu/
- Versions of WordNet for available for about 30 languages (including GermaNet with about 90.000 lexical items).
- WordNet consists of different, basically unrelated databases for common nouns, verbs, adjectives and adverbs.
- The respective hierarchies have a number of “uniqe beginners” each.

WordNet Nouns: Unique Beginners

{*act, action, activity*}
{*animal, fauna*}
{*artifact*}
{*attribute, property*}
{*body, corpus*}
{*cognition, knowledge*}
{*communication*}
{*event, happening*}
{*feeling, emotion*}
{*food*}
{*group, collection*}
{*location, place*}
{*motive*}
{*natural object*}
{*natural phenomenon*}
{*person, human being*}
{*plant, flora*}
{*possession*}
{*process*}
{*quantity, amount*}
{*relation*}
{*shape*}
{*state, condition*}
{*substance*}
{*time*}

(Miller, 1993)

About Dolphins

- 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 bottle-nose dolphin calf is about 90-130 cms long and will grow to approx. 4 meters, 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.

Common Nouns

- 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 bottle-nose dolphin calf is about 90-130 cms long and will grow to approx. 4 meters, 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.

Common Nouns + Adjectives

- 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 bottle-nose dolphin calf is about 90-130 cms long and will grow to approx. 4 meters, 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.

Common Nouns + Adjectives + Verbs

- 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 bottle-nose dolphin calf is about 90-130 cms long and will grow to approx. 4 meters, 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.

The Layer of Predicate-Argument Relations

- (Almost) Equivalent sentences with different realizations of “the same” semantic argument positions:
  - *Mary likes John*
  - *John pleases Mary*

  - *Mary gave Peter the book.*
  - *Peter received the book from Mary.*

Another Observation

- Verbs with varying number of explicit argument positions, and varying realizations of “the same” argument:
  - *The window broke*
  - *A rock broke the window*
  - *John broke the window with a rock*

  - *The plane flew to Frankfurt*
  - *John flew the plane to Frankfurt*
  - *John flew Bill with the plane to Frankfurt.*

Thematic Roles (Fillmore 1968)

- Thematic roles describe the conceptual participants in a situation in a generic way, independent from their grammatical realization.

Thematic Roles: A Textbook Example

- *John gave Mary the book.*

- *Mary received the book from John.*

Thematic Roles: A Textbook Example

- *[$_{Subj}$ John] gave [$_{DObj}$ Mary] [$_{AObj}$ the book].*

- *[$_{Subj}$ Mary] received [$_{DObj}$ the book] [$_{PObj}$ from John].*

Thematic Roles: A Textbook Example

- *John gave Mary the book.*

- *Mary received the book from John.*

Thematic Roles: A Textbook Example

- *give:* Subj ⇔ Agent
  AObj ⇔ Theme
  DObj ⇔ Recipient

- *receive:* Subj ⇔ Recipient
  AObj ⇔ Theme
  POBj from ⇔ Agent

Thematic Roles: A Textbook Example

- *[$_{Subj}$ John] gave [$_{DObj}$ Mary] [$_{AObj}$ the book].*
- *[$_{agt}$ John] gave [$_{rec}$ Mary] [$_{pat}$ the book].*

- *[$_{Subj}$ Mary] received [$_{DObj}$ the book] [$_{PObj}$ from John].*
- *[$_{rec}$ Mary] received [$_{pat}$ the book] [$_{ag}$ from John].*

Thematic Roles: A Textbook Example

- give(agt: John, pat: the book, rec: Mary)
- receive(agt: John, pat: the book, rec: Mary)

- **TRANSACTION**(agt: John, pat: the book, rec: Mary)

A More Complex Example

- 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

The Berkeley FrameNet Database

- A lexicon with thematic role information for verbs and other relational expressions. Basic unit: frames.
- Frames (like “comercial transaction”) provide:
  - Role information
  - Grammatical realization patterns (role linking)
  - Annotations of example sentences (from BNC)
- Current release: about 700 frames and 8000 lexical units (mostly verbs). Planned: 15.000 verb descriptions.
- SALSA Project: A corpus-based, large, application-oriented lexical-semantic resource based on FrameNet.

Discourse Semantics

Anaphoric Pronouns

- 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 bottle-nose dolphin calf is about 90-130 cms long and will grow to approx. 4 meters, 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.

Semantic context dependence

- 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”)

More Anaphora

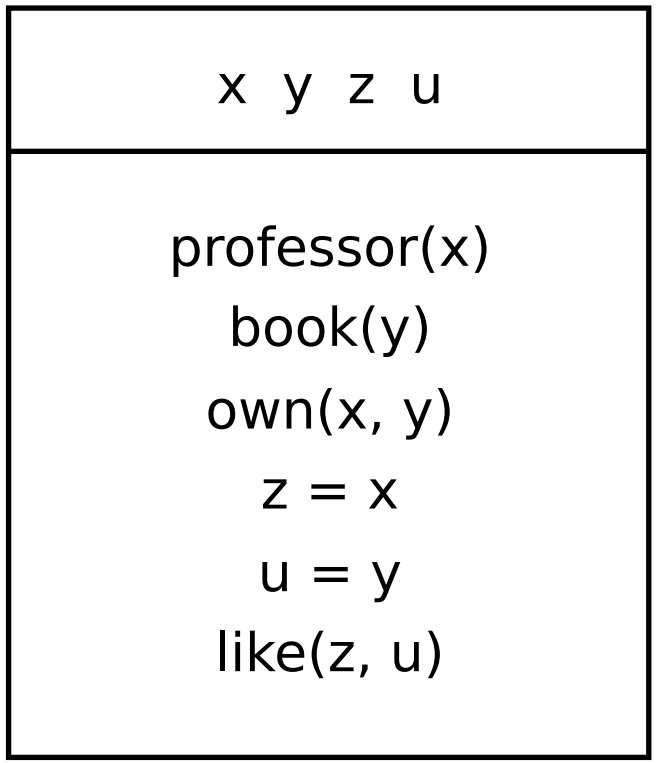
- Definite Noun Phrases (definite descriptions)
  - Some students do not own the Gamut textbook. They are reading the book in the library.
- Bridging:
  - I would like to read the logic introduction recommended for the semantics course. But I do not remember the title.

Definite and Indefinite Noun Phrases

- 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 can be used to refer to them anaphorically.
- Discourse representation theory (DRT) models this process.

Discourse Representation Theory: An Example

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



More Context Dependence

- Every student is familiar with the basic properties of FOL.
- John always comes late.
- Its hot and sunny everywhere.
- Dolphin from different pods interact from time to time.
- Bill owns an expensive car.