Semantic Theory

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Discourse Semantics - DRT

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What should a semantic theory provide?

- A framework to specify word meaning
- The composition process leading from word meanings to sentence information
- The building of a semantic discourse representation from a sequence of sentences in a text (or piece of dialogue)
- Disambiguation/ resolution mechanisms selecting the intended information of an utterance from the large number of linguistically possible interpretations
- Inference mechanisms leading from the given utterance information to other relevant information

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Dolphins in Context

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 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.

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A simple context theory (Lewis 1970/72)

- Context-dependent expressions are interpreted with respect to contexts.
- Context-dependent expressions are either
  - deictic (dependent on non-linguistic utterance situation), like *I, you, now, here,* etc., or
  - anaphoric (dependent on linguistic context/ preevious discourse): *he, she, it, then, the president,* etc.
- A context is formally modelled as a sequence of semantically relevant context data with fixed arity.
- Meanings are modelled as functions from contexts to denotations – more specifically, they are functions from certain projections of contexts (context coordinates, context features) to denotations,

An Example

- Context c = $\langle a, b, l, t, r \rangle$
  - *a* speaker — $[[I]]^{M,g,c}$ = utt(c) = *a*
  - *b* addressee — $[[you]]^{M,g,c}$ = adr(c) = *b*
  - *l* utterance location — $[[here]]^{M,g,c}$ = loc(c) = *l*
  - *t* utterance time — $[[now]]^{M,g,c}$ = time(c) = *t*
  - *r* referred object — $[[this]]^{M,g,c}$ = ref(c) = *r*

A simple type-theoretic context semantics

- Model structure: M = ⟨U, C, V⟩
  - U model universe
  - C context set
  - V value asignment function that assigns non-logical constants functions from contexts to denotations of appropriate type.
- Interpretation:
  - $[[\alpha]]^{M,h,c} = V(\alpha)(c)$, if α non-logical constant,
  - $[[\alpha]]^{M,h,c} = h(\alpha)$, if α Variable,
  - $[[\alpha(\beta_1, \ldots, \beta_n)]]^{M,h,c} = [[\alpha]]^{M,h,c}([[\beta_1]]^{M,h,c}, \ldots, [[\beta_n]]^{M,h,c})$
  - etc.

Interpretation: An example

I am reading the book ⇒ read'(the-book')(I')

$[[\text{read'(the-book')(I')}]]^{M,h,c}$ =

$[[\text{read'}]]^{M,h,c}([[\text{the-book'}]]^{M,h,c})([[\text{I'}]]^{M,h,c})$ =

V(read')(ref(c))(utt(c))

Note: context-invariant expressions are interpreted as constant functions:

V(read')(c) = V(read')(c') [= V(read')] for all c, c' ∈ C

Problems [1]

- There is no plausible upper limit to the number of context coordinates:

  Every student is familiar with the basic properties of FOL

  John always is late.

  Its hot and sunny everywhere.

  Dolphin from different pods interact from time to time.

  Bill owns an expensive car.

  Another one, please!

Problems [2]: Definite NP in standar type theory

- Standard type-theoretic representation of definite article:

  the $\Rightarrow$ $\lambda F \lambda G \exists y(\forall x(F(x) \leftrightarrow x=y) \wedge G(y))$

  the student $\Rightarrow$ $\lambda G \exists y(\forall x(student'(x) \leftrightarrow x=y) \wedge G(y))$

  the student is working $\Rightarrow$

  $\exists y(\forall x(student'(x) \leftrightarrow x=y) \wedge work'(y))$

- Truth conditions are problematic
- Truth conditions of negated sentence are even more problematic.

Problems [2]: Definite NP in simple context semantics

- Utterances typically contain noun phrases referring to different objects:

  The student is reading the book in the library

- In a given utterance situation, we can refer to different objects of the same kind by using different NP versions:

  Please, give me the book / the blue book / the book about DRT

Probleme [3]: Indefinite NP

- Standard type-theoretic analysis of indefinite NP

  a $\Rightarrow \lambda P \lambda Q \exists x[P(x) \wedge Q(x)]$

  a student $\Rightarrow \lambda Q \exists x[\text{student}'(x) \wedge Q(x)]$

  a student is working $\Rightarrow \exists x[\text{student}'(x) \wedge \text{work}'(x)]$

- Problem:

  A student is working. She is successful.

  $\Rightarrow \exists x[\text{student}'(x) \wedge \text{work}'(x)] \wedge \text{successful}'(\mathbf{x})$

  No variable binding across sentence boundaries.

Problems [4]:

- Indefinite noun phrases introduce information into context, which is available at a later stage of discourse for anaphoric reference.
- Standard type-theoretic semantics does not provide any basis for modelling this context-changing potential of indefinite NPs.
- Simple context semantics does not either.
- An additional problem:

  Someone – whoever that may be – will find out. That person will be terribly upset.

  If you have pencil or a ballpoint pen, could you please give it to me?

  Objects of anaphoric reference do not necesserily refer to a specific individual.

Basic Assumptions in Discourse Semantics

- Meaning representation uses discourse referents in addition to formulas encoding truth conditions.
- "Division of labor" between definite and indefinite NPs:
  - Indefinite NPs introduce new discourse referents
  - Definite NPs refer to "old" or "familiar" discourse referents (which are already part of the meaning representation)
- Discourse referents first proposed by Lauri Karttunen (1973)
- Discourse Representation Theory: Hans Kamp (1981), see also Kamp/Reyle text book
- File Change Semantics: Irene Heim (1982)

Discourse Representation Theory (DRT): General Text Interpretation Scheme

Text

$\Sigma = \langle\ S_1,\quad S_2,\quad \ldots,\quad S_n \rangle$

Syntactic analysis

DRS construction

K_0

Discourse Representation Theory (DRT): General Text Interpretation Scheme

Text

$\Sigma = \langle\ S_1,\quad S_2,\quad \ldots,\quad S_n \rangle$

Syntactic analysis

$\downarrow$

$P(S_1)$

DRS construction

K_0

Discourse Representation Theory (DRT): General Text Interpretation Scheme

Text

$\Sigma = \langle\ S_1,\quad S_2,\quad \ldots,\quad S_n \rangle$

Syntactic analysis

$S_1 \downarrow P(S_1)$

DRS construction

$P(S_1) \downarrow K_1$

$K_0 \rightarrow K_1$

Discourse Representation Theory (DRT): General Text Interpretation Scheme

Text

$\Sigma = \langle\ S_1,\quad S_2,\quad \ldots,\quad S_n \rangle$

Syntactic analysis

$S_1 \downarrow P(S_1) \qquad S_2 \downarrow P(S_2)$

DRS construction

$P(S_1) \downarrow K_1$

$K_0 \rightarrow K_1$

Discourse Representation Theory (DRT): General Text Interpretation Scheme

Text

$\Sigma = \langle S_1, \quad S_2, \quad \ldots, \quad S_n \rangle$

Syntactic analysis

$\downarrow \quad \downarrow$

$P(S_1) \quad P(S_2)$

DRS construction

$\downarrow \quad \downarrow$

$K_0 \rightarrow K_1 \rightarrow K_2$

Discourse Representation Theory (DRT): General Text Interpretation Scheme

Text

$\Sigma = \langle S_1, \quad S_2, \quad \ldots, \quad S_n \rangle$

Syntactic analysis

$\downarrow \quad \downarrow \quad \quad \downarrow$

$P(S_1) \quad P(S_2) \quad \ldots \quad P(S_n)$

DRS construction

$\downarrow \quad \downarrow \quad \quad \downarrow$

$K_0 \rightarrow K_1 \rightarrow K_2 \rightarrow \ldots \rightarrow K_n$

Discourse Representation Theory (DRT): General Text Interpretation Scheme

Text

$\Sigma = \langle\ S_1,\quad S_2,\quad \ldots,\quad S_n \rangle$

Syntactic analysis

$P(S_1)\quad P(S_2)\quad \ldots\quad P(S_n)$

DRS construction

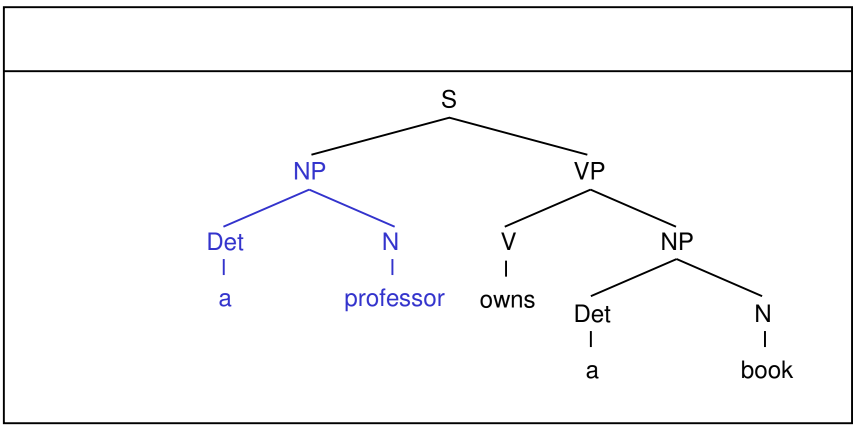
$K_0 \rightarrow K_1 \rightarrow K_2 \rightarrow \ldots \rightarrow K_n$

Interpretation by embedding:

Truth conditions of Σ

An example

- *A professor owns a book. He reads it.*

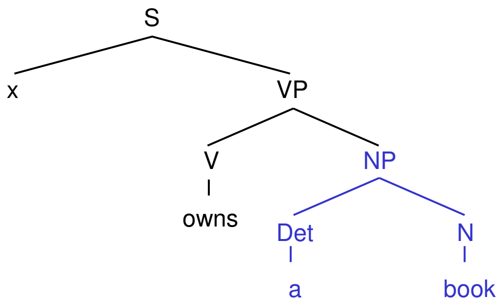


An example

- *A professor owns a book. He reads it.*

x

professor (x)

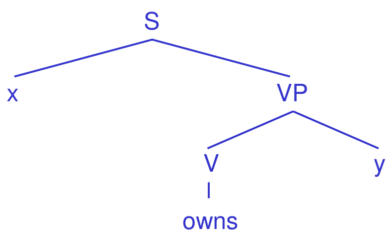


An example

- *A professor owns a book. He reads it.*

x y

professor(x)
book(y)



An example

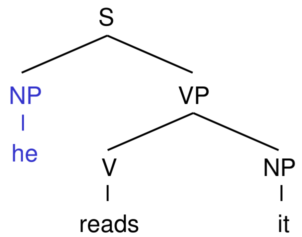
- *A professor owns a book. He reads it..*

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

An example

- *A professor owns a book. He reads it.*

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

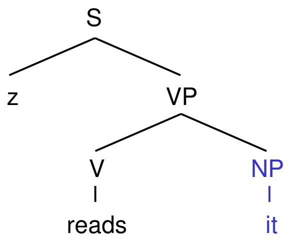


An example

- *A professor owns a book. He reads it.*

x y z

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

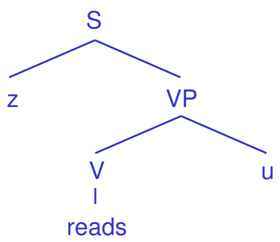


An example

- *A professor owns a book. He reads it.*

x y z u

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



An example

- *A professor owns a book. He reads it.*

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

DRS (Basic Version)

- A discourse representation structure (DRS) K is a pair $\langle U_K, C_K \rangle$, where
  - U_K is a set of discourse referents
  - C_K is a set of conditions
- (Fully reduced) conditions:
  - $R(u_1, \ldots, u_n)$ R n-place relation, $u_i \in U_K$
  - $u = v$ $u, v \in U_K$
  - $u = a$ $u \in U_K$, a is proper name
- Reducible conditions:
- Conditions of form α bzw. $\alpha(x_1, \ldots x_n)$, where α is a context-free parse tree.

DRS (Basic Version)

- A discourse referent (DR) u is free in DRS $K = \langle U_K, C_K \rangle$, if u is free in one of K's conditions, and $u \notin U_K$.
- A DRS K is closed in K iff no DR occurs free in K.
- A reducible (fully reduced) DRS is a DRS which contains (does not contain) reducible conditions.

DRS Construction Algorithm

- Input:
  - a text $\Sigma = \langle S_1, \ldots, S_n \rangle$
  - a DRS $K_0 = \langle \varnothing, \varnothing \rangle$
- Repeat for i = 1, …, n:
  - Add parse tree $P(S_i)$ to the conditions of K_{i-1}.
  - Apply DRS construction rules to reducible conditions of K_{i-1}, until no reduction steps are possible any more. The resulting DRS is K_i, the discourse representation of text $\langle S_1, \ldots, S_i \rangle$.

DRS Construction Rule for Indefinite NP

- Triggering Configuration:
  - α is reducible condition in DRS K; α contains $[_S [_{NP}\ \beta] [_{VP}\ \gamma]]$ or $[_{VP} [_V\ \gamma] [_{NP}\ \beta]]$ as a substructure.
  - β is $\varepsilon\delta$, ε is indefinite article
- Action:
  - Add a new DR x to U_K.
  - Replace β in α by x.
  - Add $\delta(x)$ to C_K.

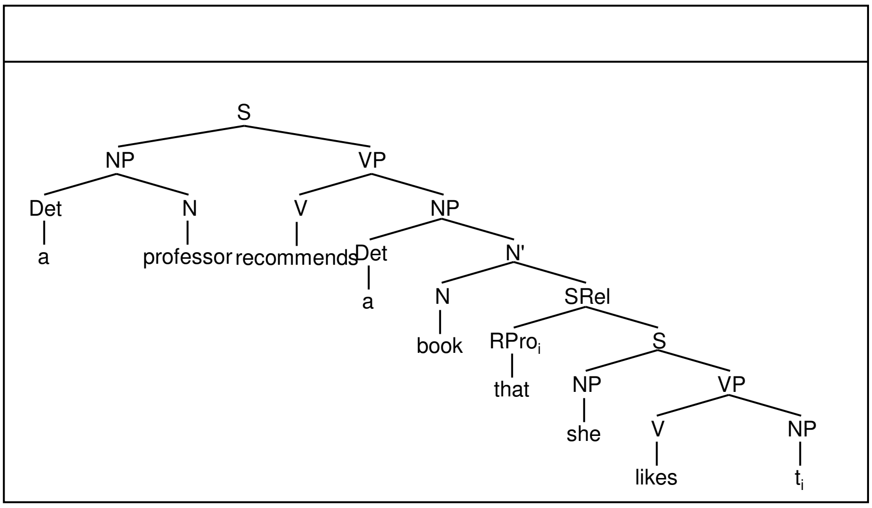
DRS Construction Rule for Personal Pronoun

- Triggering Configuration:
  - α is reducible condition in DRS K; α contains $[_S [_{NP}\ \beta] [_{VP}\ \gamma]]$ or $[_{VP} [_V\ \gamma] [_{NP}\ \beta]]$ as substructure.
  - β is a personal pronoun.
- Action:
  - Add a new DR x to U_K.
  - Replace β in α by x.
  - Select an appropriate DR $y \in U_K$, and add $x = y$ to C_K.

DRS Construction Rule for Proper Names

- Triggering Configuration:
  - α is reducible condition in DRS K; α contains $[_S [_{NP}\ \beta] [_{VP}\ \gamma]]$ or $[_{VP} [_V\ \gamma] [_{NP}\ \beta]]$ as substructure.
  - β is a proper name.
- Action:
  - Add a new DR x to U_K.
  - Replace β in α by x.
  - Add $x = \beta$ to C_K.
  - (Variant: Add $\beta(x)$ to C_K)

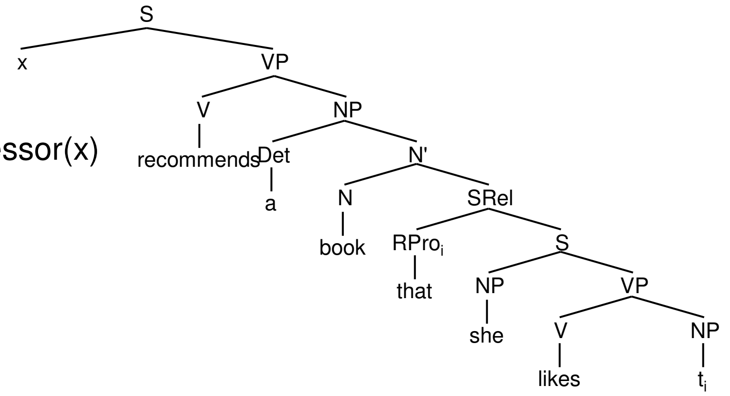
A more complex example



Indefinite NP rule

x

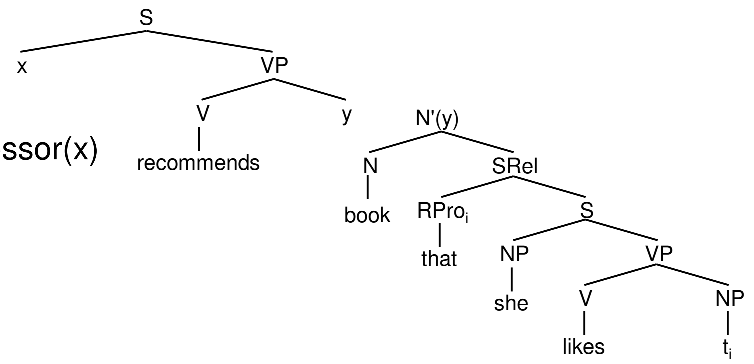
professor(x)



Indefinite NP rule

x y

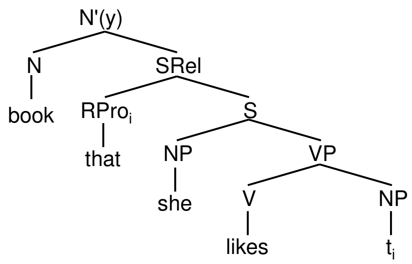
professor(x)



Flattening

x y

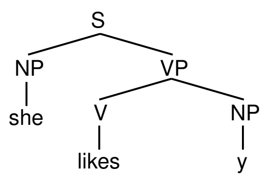
professor(x)
recommend(x, y)



Relative Clause Rule

x y

professor(x)
recommend(x, y)
book(y)



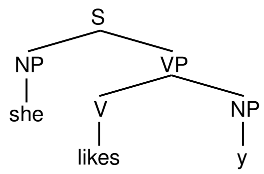
DRS Construction Rule for Relative Clauses

- Triggering configuration:
  - $\alpha(x)$ is reducible condition in DRS K; α contains $[_{N'}\, [_{N'}\, \beta]\, [_{SRel}\, \gamma]]$ as a substructure
  - γ is relative clause of the form $\delta\varepsilon$, where δ is a relative pronoun and ε a sentence with an NP gap t, δ and t are co-indexed.
- Actions:
  - Remove $\alpha(x)$ from C_K.
  - Add $\beta(x)$ to C_K .
  - Replace the NP gap in ε by x, and add the resulting structure to C_K.

Relative Clause Rule

x y

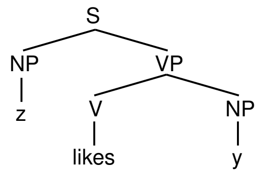
professor(x)
recommend(x, y)
book(y)



Personal Pronoun Rule

x y z

professor(x)
recommend(x, y)
book(y)
z = x



Fully reduced DRS after Flattening

x y z

professor(x)
recommends(x, y)
book(y)
z = x
likes(z, y)

A constraint on the DRS construction algorithm

- A problem: The basic DRS construction algorithm can derive DRSes for both of the following sentences, with the indicated anaphoric binding
  - *[A professor]$_i$ recommends a book that she$_i$ likes*
  - **She$_i$ recommends a book that [a professor]$_i$ likes*
- If two triggering configurations of one or two different DRS construction rules occur in a reducible condition, then first apply the construction rule to the highest triggering configuration. ("Highest Triggering Configuration Constraint")

DRT: Denotational Interpretation

- Let
  - U_D a set of discourse referent,
  - $K = \langle U_K, C_K \rangle$ a DRS with $U_K \subseteq U_D$,
  - $M = \langle U_M, V_M \rangle$ an FOL model structure appropriate for K.
- An *embedding* of K into M is a (partial) function f from U_D to U_M such that $U_K \subseteq \text{Dom}(f)$.

Verifying embedding

- An embedding f of K in M verifies K in M:

  $f \models_M K$ iff f verifies every condition $\alpha \in C_K$.

- f verfies condition α in M ($f \models_M \alpha$):

  (i) $f \models_M R(x_1,\ldots, x_n)$ iff $\langle f(x_1), \ldots , f(x_n)\rangle \in V_M(R)$

  (ii) $f \models_M x = a$ iff $f(x) = V_M(a)$

  (iii) $f \models_M x = y$ iff $f(x) = f(y)$

Truth

- Let K be a closed DRS and M be an appropriate model structure for K.

  K is true in M iff there is a verifying embedding f of K in M.

- Let D be a discourse/text, K a DRS that can be constructed from D.

  D is true with respect to K in M iff K is true in M.

- Let D be a discourse/text, which is true with respect to all DRSes that can be consructed from D:

  D is true in M iff D is true with respect to all DRSes that can be constructed from D.

Translation of DRSes to FOL

- DRS K = $\langle\{x_1, ..., x_n\}, \{c_1, ..., c_k\}\rangle$

$x_1 \ . \ . \ . \ x_n$
$c_1 \ . \ . \ . \ c_n$

is truth-conditionally equivalent to the following FOL formula:

$\exists x_1 ... \exists x_n [c_1 \wedge ... \wedge c_k]$

Basic advantages of DRT

- DRT models intra-sentential anaphoric relations by DRS-construction **plus** truth-conditional interpretation.
- In particular, DRT explains the ambivalent character of indefinite NPs: Expressions that introduce new reference objects into context, and are truth contidionally equivalent to existential quantifiers.

General Properties of DRT

- DRT is a dynamic theory of meaning:
  Meaning of an expression is described as its context change potential.
- DRT is a representational theory of meaning:
  Semantic information is more than truth conditions:
  Truth conditions + "anaphoric potential".
- DRT is non-compositional (see later).