Semantic Theory

Summer 2006

Discourse Semantics - DRT

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Dolphins in First-order Logic

Dolphins are mammals, not fish.

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

Dolphins live-in pods.

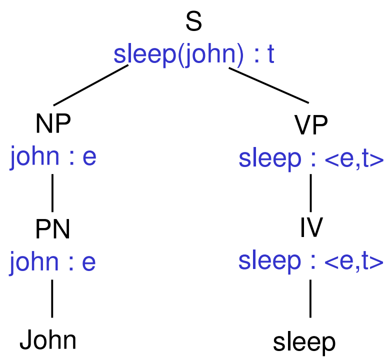
$\forall$d (dolphin'(d)$\rightarrow$ $\exists$x (pod'(p) $\wedge$ live-in'(d,p))

Dolphins give birth to one baby at a time.

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

Semantics construction

- John sleeps.



About Dolphins

Logical semantics

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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Lexical semantics

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Discourse semantics

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Structure of this course

- Sentence semantics
- Discourse semantics
- Lexical semantics

A simple context theory (Lewis 1970/72)

- Some natural-language expressions, like *I, you, here, this* must be interpreted with respect to context.
- Technically, contexts can be modelled as vectors: sequences of semantically relevant context data with fixed arity.
- Meanings can be 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 = ⟨*a*, *b*, *l*, *t*, *r*⟩
  - *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*

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 this book $\Rightarrow$ read'(this-book')(I')

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

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

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' $\in$ C

Problems [1]

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

  Every student must be 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 has bought an expensive car.

  Another one, please!

Problems [2]: Definite NPs

- Standard type-theoretic representation of definite article:

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

  the student ⇒ $\lambda G \exists y(\forall x(\mathit{student'}(x) \leftrightarrow x=y) \wedge G(y))$

  the student is working ⇒

  $\exists y(\forall x(\mathit{student'}(x) \leftrightarrow x=y) \wedge \mathit{work'}(y))$
- Truth conditions are highly problematic. Context dependent interpretation of definite NPs via "referred object" coordinate is a real step forward.

Problems [2]: Definite NPs

- But: 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 NPs

- 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.
- Indefinite noun phrases extablish the context for later reference, they introduce new reference objects.

Problems [4]:

- An additional problem:

  Someone – whoever that may be – will eventually find out. That person will tell others, and everyone will be terribly upset.

  If you have a pencil or a ballpoint pen, could you please give it to me?
- Reference objects introduced by indefinite NPs need not correspond to real objects.

Some facts about context dependence

- Many, if not all natural language expressions are context-dependent at least to some degree. – Two sub-classes:
  - deictic expressions, which depend on the physical utterance situation, like *I, you, now, here,* etc.
  - anaphoric expressions, which refer to linguistic context/ previous discourse): *he, she, it, then,* etc.
- The interpretation of most context-dependent expressions, e.g., definite noun phrases, is determined by context in a highly complex way.
- Some types of expressions, like indefinite noun phrases, introduce new context information, which is available at a later stage of discourse for anaphoric reference. Modelling of this kind of context change potential is definitely outside the reach of standard type-theoretic semantics, with of without context-semantic extension.
- The entities involved in contextual reference are not real objects, but a more abstract kind of entities.

Discourse Semantics

- Focus on anaphoric use of noun phrases (definite and indefinite, full NPs and pronouns).
- Meaning representation uses discourse referents in addition to formulas encoding truth conditions (Lauri Karttunen 1973).
- "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 Representation Theory: Hans Kamp (1981), Irene Heim (1980)
- Reading: Hans Kamp/Uwe Reyle: From Discourse to Logic, Kluwer: Dordrecht 1993.

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

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

Syntactic analysis

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

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

DRS construction

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

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

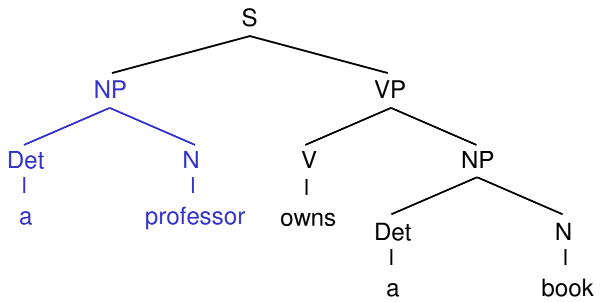
Interpretation by embedding:

$\downarrow$

Truth conditions of Σ

An example

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

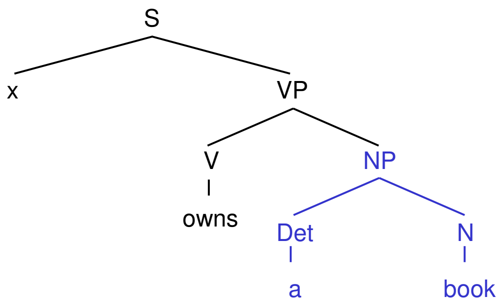


An example

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

x

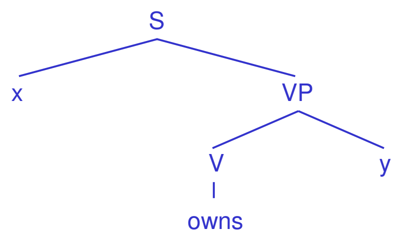
professor (x)



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..*

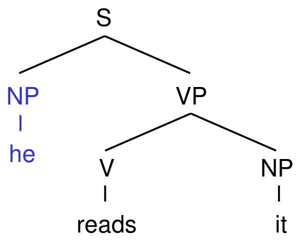
x y
professor(x) book(y) own(x, y)

An example

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

x y

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



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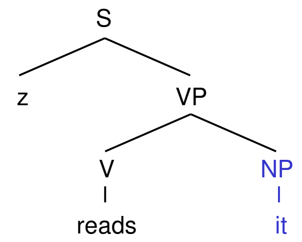
An example

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

x y z

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



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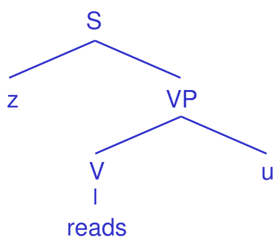
An example

- *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 or $\alpha(x_1,\ldots,x_n)$, 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 (= $\langle \emptyset, \emptyset \rangle$, by default)
- 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 indefinite article
- Action:
  - Add a new DR x to U_K.
  - Replace β in α by x.
  - Add $\delta(x)$ to C_K.

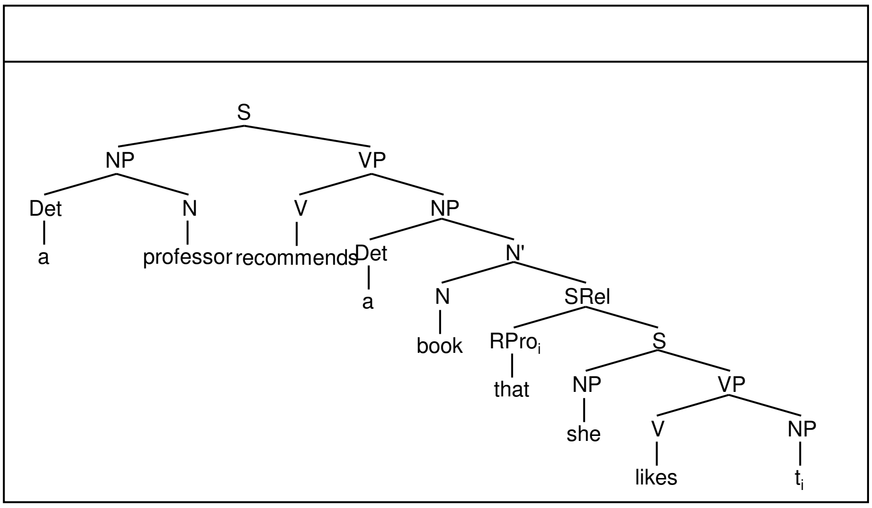
DRS Construction Rule for Personal Pronoun

- 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.

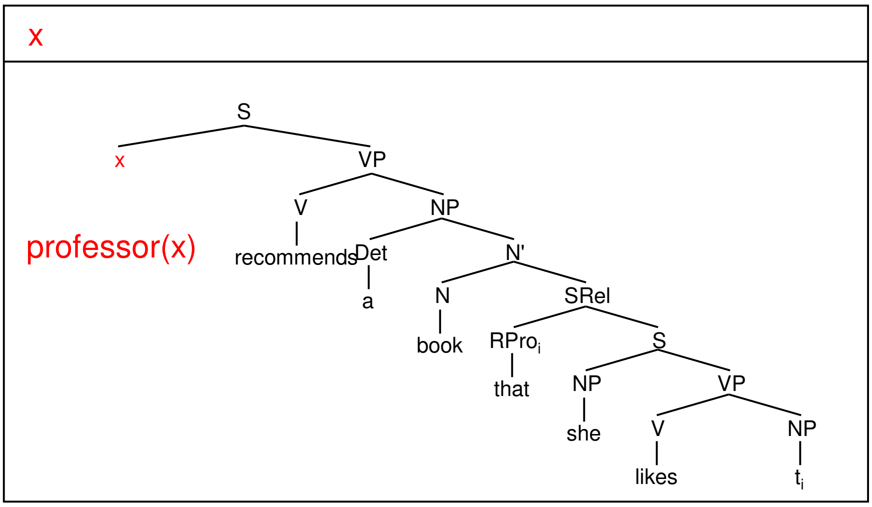
DRS Construction Rule for Proper Names

- 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



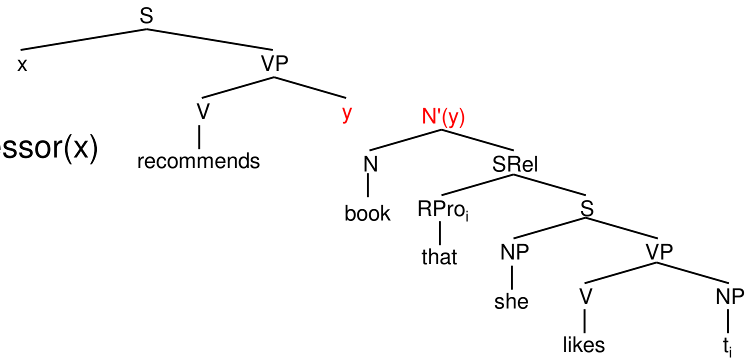
Indefinite NP rule



Indefinite NP rule

x y

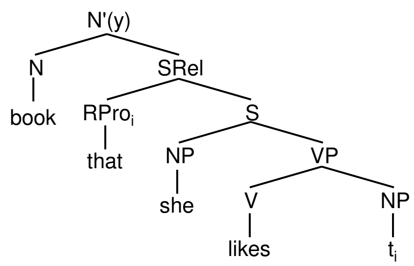
professor(x)



Flattening

x y

professor(x)
recommend(x, y)



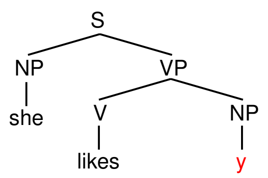
DRS Construction Rule for Relative Clauses

- 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

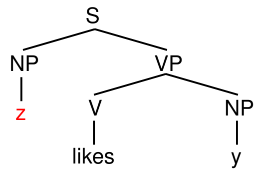
professor(x)
recommend(x, y)
book(y)



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 one. ("Highest Triggering Configuration Constraint")

Discourse Representation Theory (DRT): General Text Interpretation Scheme

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

Syntactic analysis $\quad \downarrow$

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

DRS construction $\quad \downarrow$

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DRS construction

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

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

Interpretation by embedding:

$\downarrow$

Truth conditions of Σ

DRT: Denotational Interpretation

- Let
  - U_D a set of discourse referents,
  - $K = \langle U_K, C_K \rangle$ 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 $U_K \subseteq Dom(f)$.

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.