Semantic Theory: Discourse Representation Theory I

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Structure of the Course

- Part I: Sentence semantics
  - Type theoretic semantics, scope, and underspecification
- Part II: Discourse Semantics
  - Anaphora and Coreference, Discourse Representation Theory, Presuppositions
- Part III: Lexical Semantics
  - Event and Frame Semantics, Metaphor and Metonymy, Generative Lexicon

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 are modelled as vectors: sequences 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*

Simple type-theoretic context semantics

- Model structure: M = ⟨U, C, V⟩
  - U model universe
  - C context set
  - V value assignment 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,
  - $[[\alpha(\beta_1, \dots, \beta_n)]]^{M,h,c} = [[\alpha]]^{M,h,c}([[\beta_1]]^{M,h,c}, \dots, [[\beta_n]]^{M,h,c})$
  - etc.

Interpretation: An example

I am reading this book ⇒ 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' ∈ 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]

- Utterances typically contain several noun phrases referring to different objects:

  The student is reading the book in the library
- Reference objects in discourse need not be real objects:

  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 pass it to me?

Does type-theoretic semantics help?

- 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 – existence of one and only one student - are inadequate.

Where does context information come from?

- *A student is working. She is successful.*
- Indefinite noun phrases establish the context for later reference, they introduce new reference objects.
- The simple coordinate approach to context semantics does not provide any help.
- Standard type-theoretic analysis of indefinite NP is also inappropriate:

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

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

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

  she $\Rightarrow$ $\lambda P P(x)$

  she is successful $\Rightarrow$ $successful'(x)$

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

- Variable representing anaphoric pronoun is unbound.

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 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 this kind of context change potential is 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

- Meaning as Context Change Potential
- 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)

Text $\sum = \langle S_1, \; S_2, \; \ldots, \; S_n \rangle$

Syntactic analysis $P(S_1)\, P(S_2) \ldots P(S_n)$

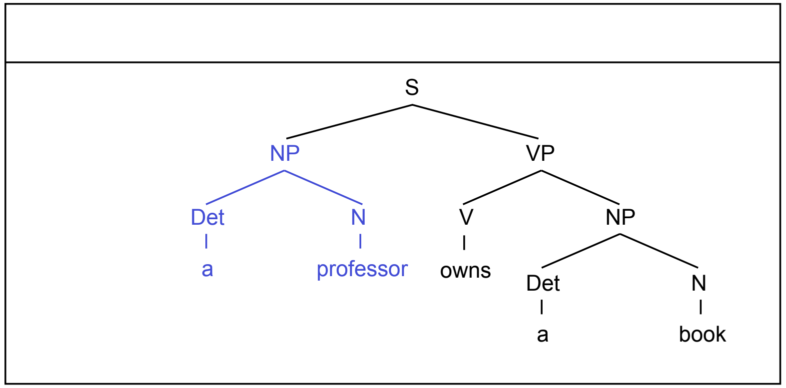
DRS construction $K_0 \rightarrow K_1 \rightarrow K_2 \rightarrow \ldots \rightarrow K_n$

Interpretation by model embedding:

Truth conditions of $\sum$

An example

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



An example

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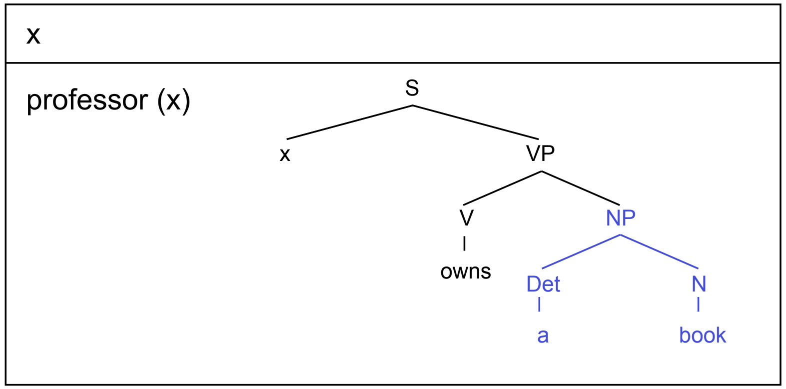

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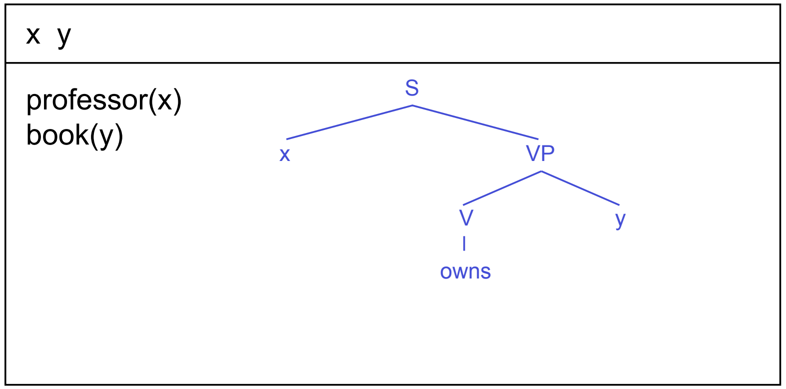

An example

- *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.*

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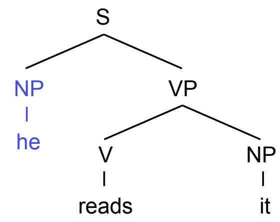
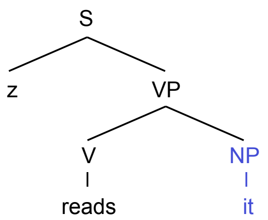


An example

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

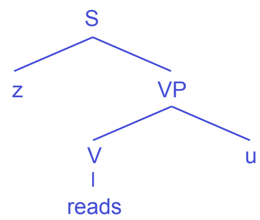
x y z
professor(x) book(y) own(x, y) z = x



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 (= $\langle \varnothing, \varnothing \rangle$, 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, containing $[_S[_{NP}\ \beta]\ [_{VP}\ \gamma]]$ 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.

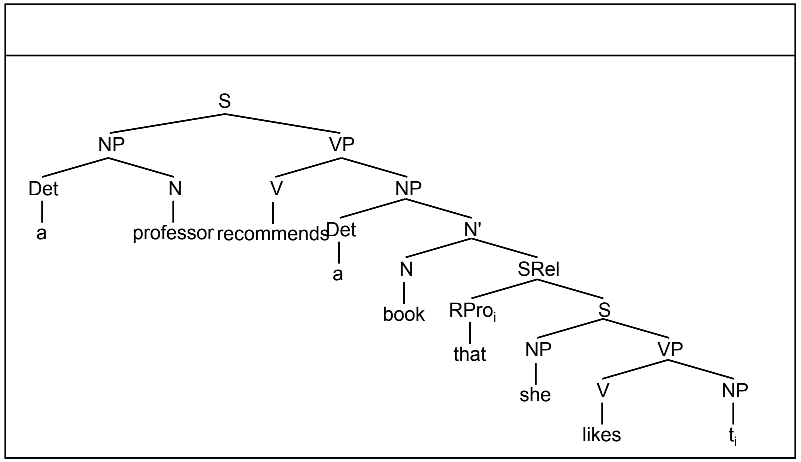
DRS Construction Rule for Personal Pronoun

- 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 = β to C_K.
  - (Variant: Add $\beta(x)$ to C_K)

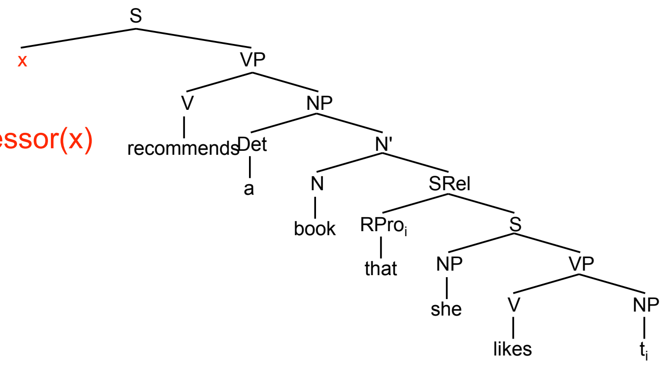
A more complex example



Indefinite NP rule

x

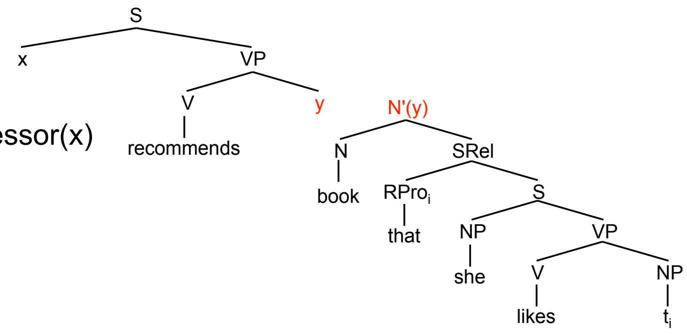
professor(x)



Indefinite NP rule

x y

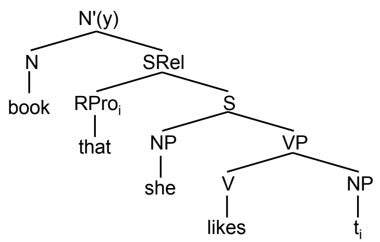
professor(x)



Flattening

x y

professor(x)
recommend(x, y)



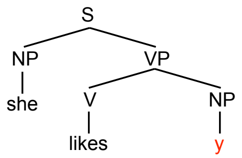
DRS-CR for Relative Clauses

- Triggering configuration:
  - α(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 α(x) from C_K.
  - Add β(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

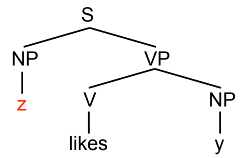
professor(x)
recommend(x, y)
book(y)



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 the construction triggered by the highest one must be executed first.

The Highest Triggering Configuration Constraint

- 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.
- The highest triggering configuration is the one whose top node dominates the top nodes of all other triggering configurations.

Discourse Representation Theory (DRT)

Text $\sum = \langle S_1, S_2, \ldots, S_n \rangle$

↓ ↓ ↓

Syntactic analysis $P(S_1)\ P(S_2) \ldots P(S_n)$

↓ ↓ ↓

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

↓

Interpretation by model embedding:

Truth conditions of $\sum$

DRT: Denotational Interpretation

- Let
  - U_D a set of discourse referents,
  - $K = \langle U_K, C_K \rangle$ a DRS with $U_K \subseteq U_D$,
  - $M = \langle U_M, V_M \rangle$ a 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 $f(x) = f(y)$

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)

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

$x_1 \ldots x_n$
$c_1 \ldots c_n$

is truth-conditionally equivalent to the following FOL formula:

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

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.