Semantic Theory: Discourse Semantics I

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A simple context theory

- Some natural-language expressions, like *I, you, here, this,* vary their meaning with context.
- Model contexts as vectors: sequences of semantically relevant context data with fixed arity.
- Model meanings as functions from contexts to denotations - more specifically, as functions from specific context components 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*

Type-theoretic context semantics

- Model structure: M = $\langle U, C, V\rangle$
  - 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 $\Rightarrow$ 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))

Context-invariant expressions are constant functions:

V(read')(c) = V(read')(c') [= V(read')] for all c, c' $\in$ C

Two basic classes of context dependent expressions

- Deictic expressions depend on the physical utterance situation:

  I, you, now, here, this

- Anaphoric expressions refer to linguistic context/ previous discourse:

  he, she, it, then

- But there is more ...

More context-dependent expressions

- Semantic context dependence is a pervasive property of natural language:

  Every student must be familiar with the basic properties of FOL

  It is hot and sunny everywhere.

  John always is late.

  Bill has bought an expensive car.

  Another one, please!

  The student is working.

Definite NPs: Type-theoretic analysis

- 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 sun $\Rightarrow$ $\lambda G \exists y(\forall x(sun'(x) \leftrightarrow x=y) \wedge G(y))$

  the sun is shining $\Rightarrow$

  $\exists y(\forall x(sun'(x) \leftrightarrow x=y) \wedge shine'(y))$

  the student is working $\Rightarrow$

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

- Definite NPs pick an appropriate object from context.

Context-dependence of definite NPs

- Definite NPs pick an appropriate object from context.
  The student is working
- Utterances typically contain several noun phrases referring to different objects:
  The student is reading the book in the library
- Noun phrases may refer to different objects of the same type, in one utterance situation:
  the book
  the blue book
  the blue book about discourse semantics

Indefinite NPs

- *A student is working*
- Standard type-theoretic analysis:
  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 $\Rightarrow \exists x[student'(x) \wedge work'(x)]$
- *A student is working. The student/ She is successful.*
- Indefinite noun phrases establish the context for later reference, they introduce new reference objects. Type-theoretic semantics cannot model this effect (without serious changes).
  she $\Rightarrow \lambda P P(x)$
  She is successful $\Rightarrow$ successful'(x)
  A student is working. She is sucessful.
  $\Rightarrow \exists x[student'(x) \wedge work'(x)] \wedge successful'(x)$

The interaction of definite and indefinite NPs

- Natural-language meaning and context interact in two ways:
  - Context determines the utterance meaning.
  - The semantics of the utterance changes the context.
- The „context change potential" is part of the meaning of natural-language expressions.

Context dependence: Wrap up

- 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.
- Reference objects established in discourse need not be real objects:
  Once upon a time there was a king, who had a beautiful daughter.
  Someone - whoever that may be - will eventually find out. That person will tell others, and everyone will be terribly upset.

Discourse Semantics

- The basic idea: 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.
- "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 $\Sigma = \langle S_1, \quad S_2, \quad ..., \quad S_n \rangle$

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

Syntactic analysis $P(S_1) P(S_2) \quad ... \quad P(S_n)$

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

DRS construction $K_0 \longrightarrow K_1 \longrightarrow K_2 \longrightarrow ... \longrightarrow K_n$

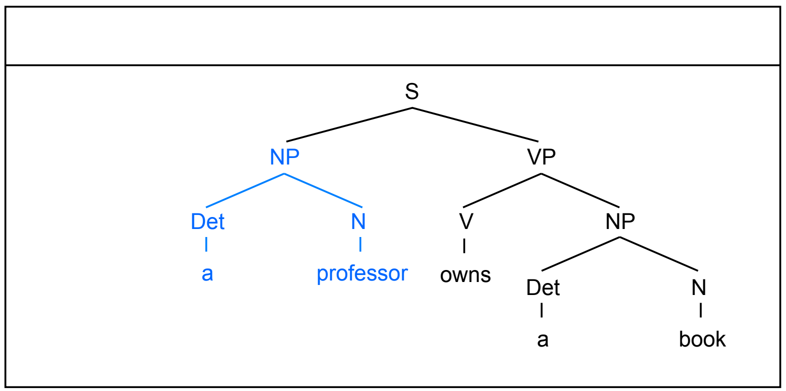
$\downarrow$

Interpretation by model embedding:

Truth conditions of Σ

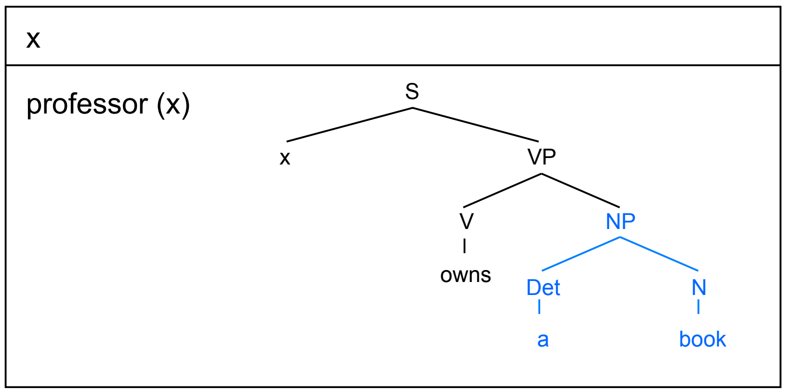
An example

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



An example

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

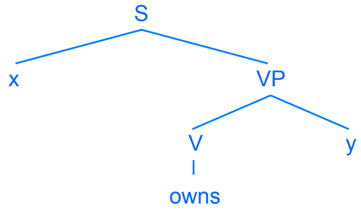


An example

- *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

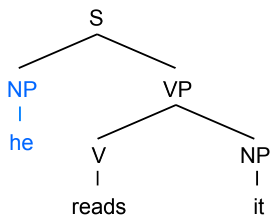
professor(x)
book(y)
own(x, y)

An example

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

x y

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

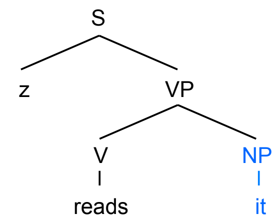


An example

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

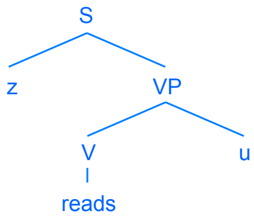
x y z

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 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 $\Sigma = \langle S_1, \dots, S_n \rangle$
  - 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 $\langle S_1, \dots, S_i \rangle$.

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.

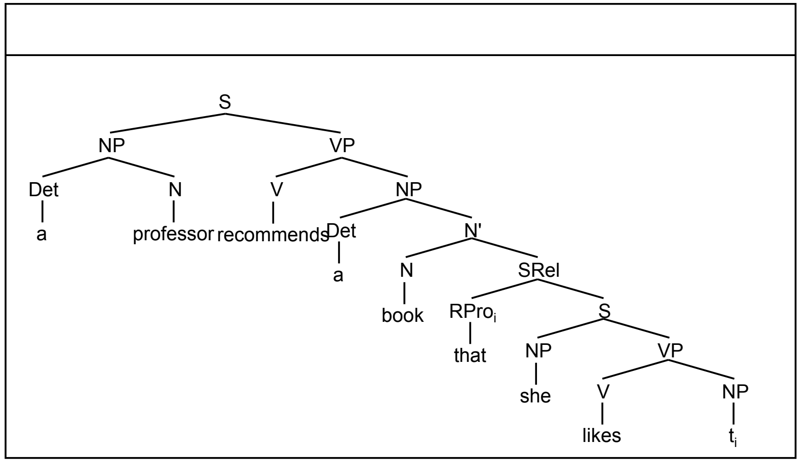
- Action:
  - Add a new DR x to U_K.
  - Replace β in α by x.
  - Select an appropriate DR $y \in U_K$, and add x = y to C_K.

DRS Construction Rule for Proper Names

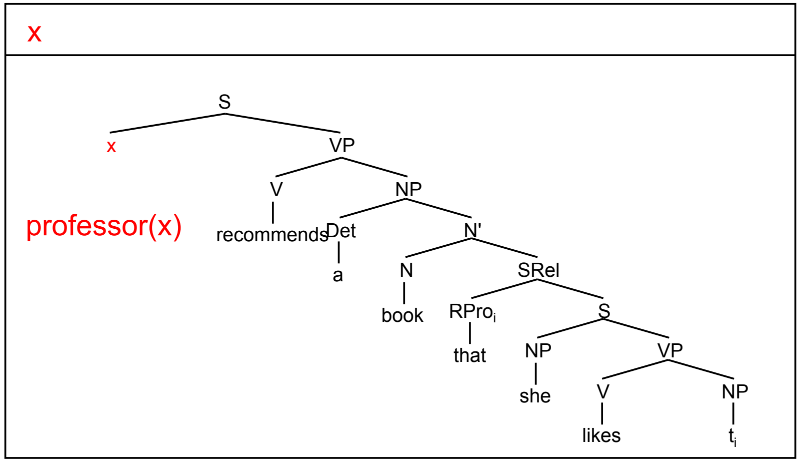
- Triggering Configuration:
  - α is reducible condition in DRS K; α contains $[_S\, [_{NP}\, \beta]\ [_{VP}\, \gamma]]$ or $[_{VP}\, [_V\, \gamma]\ [_{NP}\, \beta]]$ as substructure.
  - β is a proper name.

- Action:
  - Add a new DR x to U_K.
  - Replace β in α by x.
  - Add $x = \beta$ to C_K.

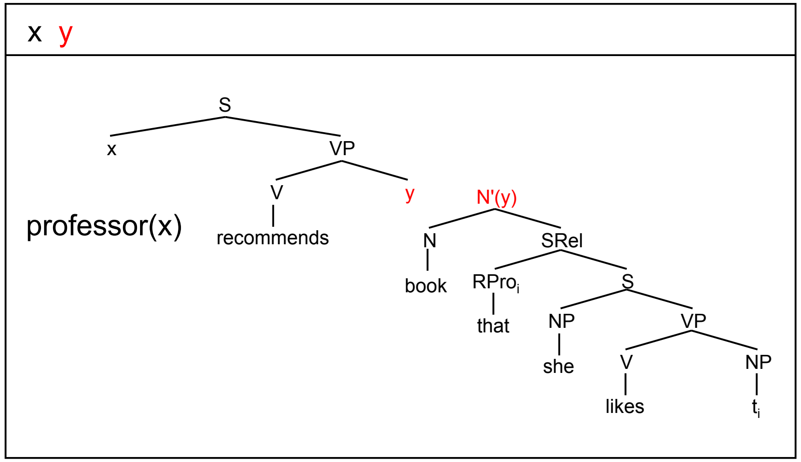
A more complex example



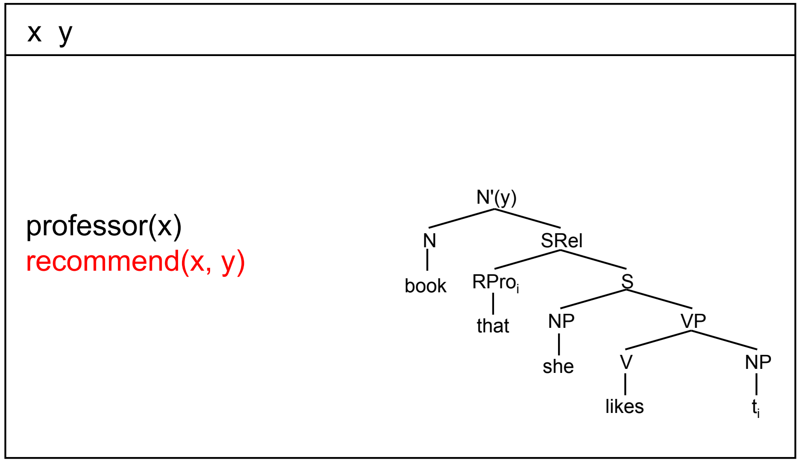
Indefinite NP rule



Indefinite NP rule



Flattening



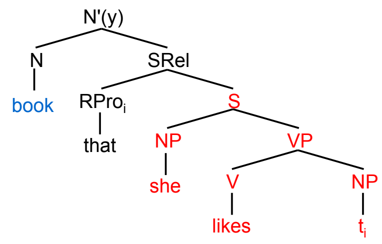
DRS-CR for Relative Clauses

- 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.

Flattening

x y

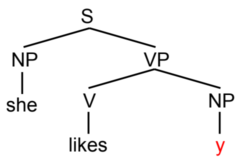
professor(x)
recommend(x, y)



Relative Clause Rule

x y

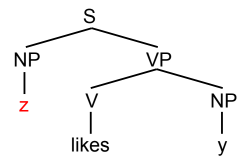
professor(x)
recommend(x, y)
book(y)



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*

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

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

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

Interpretation by model embedding:

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 $U_K \subseteq U_D$,
  - $M = \langle U_M, V_M \rangle$ 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 verifies condition α in M ($f \models_M \alpha$):
  - (i) $f \models_M R(x_1,\dots, x_n)$ iff $\langle f(x_1), \dots , f(x_n)\rangle \in V_M(R)$
  - (ii) $f \models_M x = a$ iff $f(x) = V_M(a)$
  - (iii) $f \models_M x = y$ iff $f(x) = f(y)$

Example Computation

Let K be the example DRS from above:
K = < {x, y, z, u},
{professor(x), book(y), own(x,y), read(z,u), z=x, u=y} >

$f \models_M K$ iff f verifies every condition $\alpha \in C_K$, i.e.:
$f \models_M professor(x) \wedge f \models_M book(y)\ f \models_M \wedge\ own(x,y) \wedge$
$f \models_M read(z,u) \wedge f \models_M z=x \wedge f \models_M u=y$
which holds iff:
$f(x)\in V_M(professor) \wedge f(y)\in V_M(book) \wedge \langle f(x), f(y)\rangle \in V_M(own) \wedge$
$\langle f(z), f(u)\rangle \in V_M(read) \wedge f(z)=f(x) \wedge f(u)=f(y)$

Simplification

$f \models_M K$ iff

$f(x)\in V_M(professor) \wedge f(y)\in V_M(book) \wedge \langle f(x), f(y)\rangle \in V_M(own) \wedge$
$\langle f(z), f(u)\rangle \in V_M(read) \wedge f(z) = f(x) \wedge f(u) = f(y)$
iff
$f(x)\in V_M(professor) \wedge f(y)\in V_M(book) \wedge \langle f(x), f(y)\rangle \in V_M(own) \wedge$
$\langle f(x), f(u)\rangle \in V_M(read) \wedge f(u) = f(y)$

Simplification

$f \models_M K$ iff

$f(x) \in V_M(\text{professor}) \wedge f(y) \in V_M(\text{book}) \wedge \langle f(x), f(y)\rangle \in V_M(\text{own}) \wedge$
$\quad \langle f(z), f(u)\rangle \in V_M(\text{read}) \wedge f(z) = f(x) \wedge f(u) = f(y)$

iff

$f(x) \in V_M(\text{professor}) \wedge f(y) \in V_M(\text{book}) \wedge \langle f(x), f(y)\rangle \in V_M(\text{own}) \wedge$
$\quad \langle f(x), f(u)\rangle \in V_M(\text{read}) \wedge f(u) = f(y)$

iff

$f(x) \in V_M(\text{professor}) \wedge f(y) \in V_M(\text{book}) \wedge \langle f(x), f(y)\rangle \in V_M(\text{own}) \wedge$
$\quad \langle f(x), f(y)\rangle \in V_M(\text{read})$

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 such that $Dom(f) = U_K$

Basic features of DRT

- DRT models linguistic meaning as anaphoric potential (through DRS construction) plus truth conditions (through model embedding).
- In particular, DRT explains the ambivalent character of indefinite NPs: Expressions that introduce new reference objects into context, and are truth conditionally equivalent to existential quantifiers.

Translation of DRSes to FOL

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

$$\begin{array}{|l|}\hline x_1 \ldots x_n \\ \hline c_1 \ldots c_n \\ \hline \end{array}$$

is truth-conditionally equivalent to the following FOL formula:

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