Semantic Theory

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Discourse Semantics - DRT

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Discourse Representation Theory (DRT): General Text Interpretation Scheme

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

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

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

Interpretation by embedding: $\downarrow$

Truth conditions of Σ

DRT: Denotational Interpretation

- Let
  - U_D a set of discourse 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 $U_K \subseteq Dom(f)$.

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:

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

"Highest Triggering Configuration" Again

- Highest Triggering Configuration: A mopre precise version.
- 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.

DRT: A first extension

Indefinite NPs and conditional sentences:

- *If an error occurs, the computer crashes.*

  (1) $\exists x[\text{error}(x) \,\&\, \text{occurs}(x)] \rightarrow \text{Crash}$

  (2) $\forall x[\text{error}(x) \,\&\, \text{occurs}(x) \rightarrow \text{Crash}]$
- The formulas (1) and (2) are logically equivalent:

  $\exists xA \rightarrow B \Leftrightarrow \forall x[A \rightarrow B]$

  if x doesn't occur as a free variable in B.
- So far, so good.

Indefinite NPs and conditionals: The problem

- *If an error occurs, it is displayed.*
  (1) $\exists x[error(x) \& occurs(x)] \rightarrow display(x)$
  (2) $\exists x[error(x) \& occurs(x) \rightarrow display(x)]$
  (3) $\forall x[error(x) \& occurs(x) \rightarrow display(x)]$

Indefinite NPs and conditionals: The problem

- *If an error occurs, it is displayed.*
  (1) $\exists x[error(x) \& occurs(x)] \rightarrow display(x)$
  (2) $\exists x[error(x) \& occurs(x) \rightarrow display(x)]$
  (3) $\forall x[error(x) \& occurs(x) \rightarrow display(x)]$
- Problems: (1) is not a sentence; (2) has wrong truth conditions (much too weak); (3) is correct, but how do you derive this compositionally?
- This is called the donkey sentence problem, with reference to the classical example by P.T. Geach (1967): *If a farmer owns a donkey, he beats it.*

Context-dependent interpretation of indefinites

- *A car is parked in front of Peter's garage. Peter needs to get to the office quickly. He doesn't know who owns the car. He calls the police, and the car is towed away.*
- *Suppose a car is parked in front of Peter's garage. Peter needs to get to the office quickly. He doesn't know who owns the car. Then he will call the police, and the car will be towed away.*
- *Let a and b be two positive integers. Let b further be even. Then the product of a and b is even too.*

Context-dependent interpretation of indefinites

- Indefinites must be interpreted differently (i.e., existentially or universally) depending on the context in which they are used.
- Sometimes the context only becomes clear several sentences later.
- Is it possible to construct such different representations compositionally?
- We will now see how the problem can be solved in DRT.

Conditional DRS: An example

- *If a professor owns a book, he reads it.*

a professor owns a book	⇒	he reads it

An example

- *If a professor owns a book, he reads it.*

x y		z v
professor(x) book(y) owns(x, y)	⇒	reads(z, v) z = x v = y

DRS (1. Extension)

- 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
- (Irreducible) 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 a proper name
  - $K_1 \Rightarrow K_2$ — K_1 and K_2 DRSs
- Reducible conditions: as before

DRS Construction Rule for Conditionals

- Triggering configuration:
  - α is a reducible condition in DRS K of the form $[_S \text{ if } [_S \beta] \text{ (then) } [_S \gamma]]$
- Action:
  - Remove α from C_K.
  - Add $K_1 \Rightarrow K_2$ to C_K, where
    - $K_1 = \langle \varnothing, \{ \beta \} \rangle$ and
    - $K_2 = \langle \varnothing, \{ \gamma \} \rangle$
- Remark: $K_1 \Rightarrow K_2$ is called a duplex condition; K_1 is the "antecedent DRS" and K_2 the "consequent DRS".

Recap: DRT Embeddings

- 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 embeddings for conditionals (preliminary)

- An embedding f of K into 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) $f \models_M R(x_1,\ldots, x_n)$ 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 $f(x) = f(y)$

  (iv) $f \models_M K_1 \Rightarrow K_2$ iff

  for all $g \supseteq f$ s.t. $Dom(g) = Dom(f) \cup U_{K_1}$ and $g \models_M K_1$, we also have $g \models_M K_2$

The definition seems to work ...

- *If a professor owns a book, he reads it.*

x y		
professor(x) book(y) owns(x, y)	$\Rightarrow$	reads(x, y)

... but it doesn't really!

- *If a professor owns a book, he reads it.*

x y		z v
professor(x) book(y) owns(x, y)	$\Rightarrow$	reads(z, v) z = x v = y

A more complex example

- *Peter is-a professor.*
  If he owns a book, he gives it to a student.

u

u = Peter
professor(u)

x y		z v w
x = u book (y) owns (x, y)	$\Rightarrow$	gives(z,v,w) z = x v = y student(w)

Notation: Extending embeddings

Let f, g be partial functions (embeddings) on U_D;

$U \subseteq U_D$; x, y $\in U_D$

We write

- $f \supseteq_U g$ for "$f \supseteq g$ and Dom(f) = Dom(g) $\cup$ U"
- $f \supseteq_{\{x1, ..., xn\}} g$ for
  "$f \supseteq g$ and Dom(f) = Dom(g) $\cup \{x_1, ..., x_n\}$"
- $f \supseteq_x g$ for "$f \supseteq_{\{x\}} g$".

So we can write (iv) as follows:

(iv) $f \models_M K_1 \Rightarrow K_2$ iff
for all $g \supseteq_{U_{K_1}} f$ s.t. $g \models_M K_1$, we have $g \models_M K_2$

Verifying embeddings for conditionals (final)

- An embedding f of K into 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)	$f \models_M R(x_1,\ldots, x_n)$	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	$f(x) = f(y)$
(iv)	$f \models_M K_1 \Rightarrow K_2$	iff	for all $g \supseteq_{U_{K_1}} f$ s.t. $g \models_M K_1$ there is a $h \supseteq_{U_{K_2}} g$ s.t. $h \models_M K_2$

DRS construction rule for universal NPs

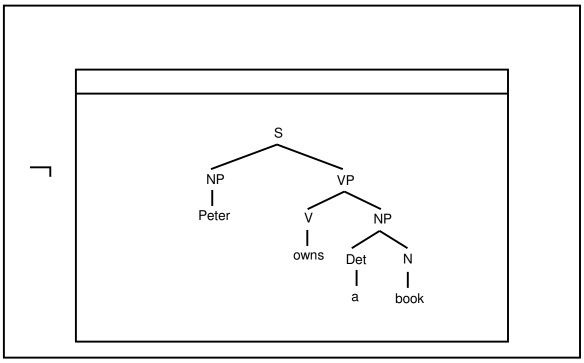
- Triggering configuration:
  - α is a reducible condition in DRS K; α contains a subtree $[_S [_{NP} \beta] [_{VP} \gamma]]$ or $[_{VP} [_V \gamma] [_{NP} \beta]]$
  - β = every δ
- Action:
  - Remove α from C_K.
  - Add $K_1 \Rightarrow K_2$ to C_K, where
    - $K_1 = \langle\{x\}, \{\delta(x)\}\rangle$ and
    - $K_2 = \langle\varnothing, \{\alpha'\}\rangle$
    - obtain α' from α by replacing β by x

DRS construction rule for negations

- Triggering configuration:
  - α is a reducible condition in DRS K of the form $[_S\ \beta\ [_{VP'}\ \text{doesn't}\ [_{VP}\ \gamma]]]$
- Action:
  - Remove α from C_K .
  - Add $\neg K_1$ to C_K, where $K_1 = \langle \emptyset, \{[_S\ \beta\ [_{VP}\ \gamma]]\}\rangle$

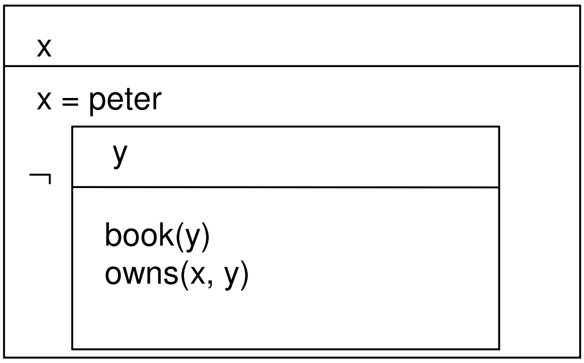
An example

- *Peter doesn't own a book.*



An example

- *Peter doesn't own a book.*



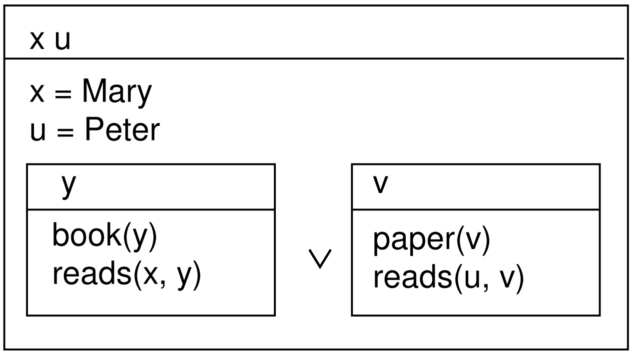
For the position of the material contributed by the proper name see the final version of the construction rule below!

DRS construction rule for sentence disjunction

- Triggering configuration:
  - α is a reducible condition in DRS K of the form $[_S [_S \beta]$ or $[_S \gamma]]$
- Action:
  - Remove α from C_K.
  - Add $K_1 \vee K_2$ to C_K, where
    - $K_1 = \langle\emptyset, \{\beta\}\rangle$ and
    - $K_2 = \langle\emptyset, \{\gamma\}\rangle$

An example

- Mary reads a book, or Peter reads a paper.



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DRS (2. Extension)

- 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
- (Irreducible) 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 a proper name
  - $K_1 \Rightarrow K_2$ K_1 and K_2 DRSs
  - $K_1 \vee K_2$ K_1 und K_2 DRSs
  - $\neg K_1$ K_1 DRS

Verifying embeddings

- f verifies 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 $f(x) = f(y)$

(iv) $f \models_M K_1 \Rightarrow K_2$ iff for all $g \supseteq_{U_{K_1}} f$ s.t. $g \models_M K_1$ there is a $h \supseteq_{U_{K_2}} g$ s.t. $h \models_M K_2$

(v) $f \models_M \neg K_1$ iff there is no $g \supseteq_{U_{K_1}} f$ s.t. $g \models_M K_1$

(vi) $f \models_M K_1 \vee K_2$ iff there is a $g_1 \supseteq_{U_{K_1}} f$ s.t. $g_1 \models_M K_1$ or there is a $g_2 \supseteq_{U_{K_2}} f$ s.t. $g_2 \models_M K_2$

Translation of DRT to FOL

- DRSs

$T(\langle\{u_1, \ldots, u_n\}, \{c_1, \ldots, c_n\}\rangle) = \exists u_1 \ldots \exists u_n[T(c_1) \wedge \ldots \wedge T(c_n)]$

- Conditions:

$T(c) = c$ (c atomic condition)

$T(\neg K_1) = \neg T(K_1)$

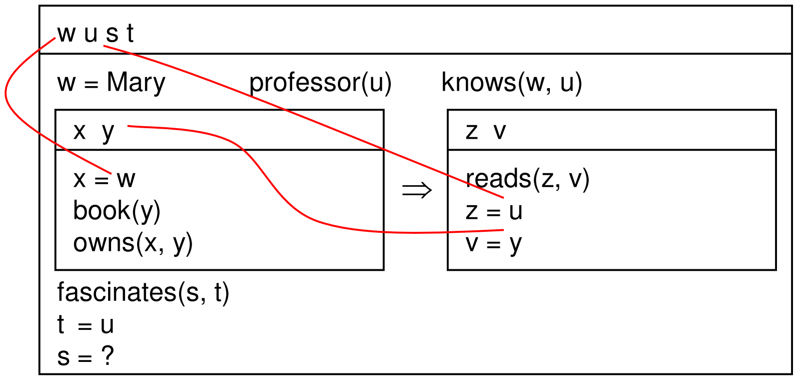
$T(K_1 \vee K_2) = T(K_1) \vee T(K_2)$

$T(K_1 \Rightarrow K_2) = \forall u_1 \ldots \forall u_n[(T(c_1) \wedge \ldots \wedge T(c_n)) \Rightarrow T(K_2)]$, if $K_1 = \langle\{u_1, \ldots , u_n\}, \{c_1, \ldots , c_n\}\rangle$

- For every closed DRS K and every appropriate model M, it can be shown that K is true in M iff T(K) is true in M.

Anaphora and accessibility

- ** Mary knows a professor. If she owns a book, he reads it. It fascinates him.*



Anaphora and accessibility

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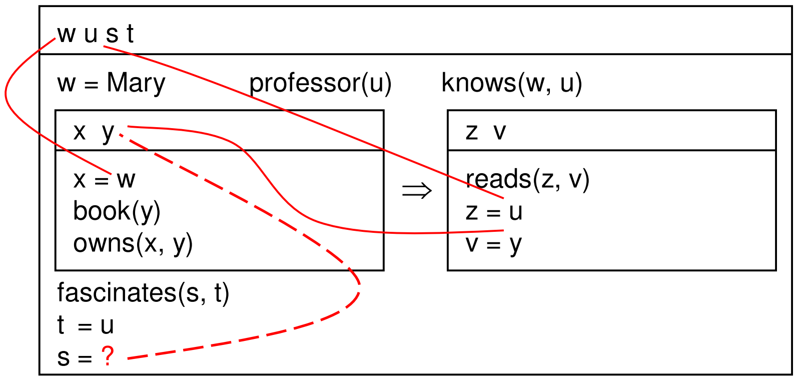

Accessible discourse referents

- The following discourse referents are accessible:
  - DRs in the same local DRS
  - DRs in a superordinate DRS
  - DRs in an antecedent DRS from the consequent DRS.

Accessible discourse referents

- Cases of non-accessibility:
  - *If a professor owns a book, he reads it. It has 300 pages.*
  - *It is not the case that a professor owns a book. He reads it.*
  - *Every professor owns a book. He reads it.*
  - *If every professor owns a book, he reads it.*
  - *Peter owns a book, or Mary reads it.*
  - *Peter owns a book, or Mary owns a CD. He hasn't read it yet.*

Subordination

- A DRS K_1 is an immediate sub-DRS of a DRS $K = \langle U_K, C_K \rangle$ iff C_K contains a condition of the form $\neg K_1$, $K_1 \Rightarrow K_2$, $K_2 \Rightarrow K_1$, $K_1 \vee K_2$ or $K_2 \vee K_1$.
- K_1 is a sub-DRS of K (notation: $K_1 \leq K$) iff
  (i) $K_1 = K$ or
  (ii) K_1 is an immediate sub-DRS of K or
  (iii) there is a DRS K_2 s.t. $K_2 \leq K_1$ and K_1 is an immediate sub-DRS of K.
  (i.e. reflexive, transitive closure)
- K_1 is a proper sub-DRS of K iff $K_1 \leq K$ and $K_1 \neq K$.

Accessibility

- Let K, K_1, K_2 be DRSs s.t. $K_1, K_2 \leq K$, $x \in U_{K_1}$, $\gamma \in C_{K_2}$
- x is accessible from γ in K iff
  (i) $K_2 \leq K_1$ or
  (ii) there are $K_3, K_4 \leq K$ s.t. $K_1 \Rightarrow K_3 \in C_{K_4}$ and $K_2 \leq K_3$

DRS Construction Rule for Personal Pronouns

- 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
  - Let K* be the main DRS that contains K.
- Action:
  - Add a new DR x to U_K.
  - Replace β in α by x.
  - Select an appropriate DR y that is accessible from α in 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
  - Let K* be the main DRS that contains K.
- Action:
  - Add a new DR x to U_{K^*}.
  - Replace β in α by x.
  - Add x = β to C_{K^*}.

Is accessibility a truth-conditional property?

If Peter owns a book, he reads it.

? If it is not the case that Peter doesn't own a book,
then he reads it.

One of the ten balls is not in the bag. It is under the sofa.

? Nine of the ten balls are in the bag. It is under the sofa.