

Semantic Theory
Summer 2005
Discourse Semantics - DRT

M. Pinkal / A. Koller

Outline

- Extending DRT:
 - conditionals
 - negation and disjunction
- Anaphora and accessibility
- Factors in anaphora resolution

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) $\exists x[\text{error}(x) \ \& \ \text{occurs}(x)] \rightarrow \text{display}(x)$
 - (2) $\exists x[\text{error}(x) \ \& \ \text{occurs}(x) \rightarrow \text{display}(x)]$
 - (3) $\forall x[\text{error}(x) \ \& \ \text{occurs}(x) \rightarrow \text{display}(x)]$

Indefinite NPs and conditionals: The problem

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

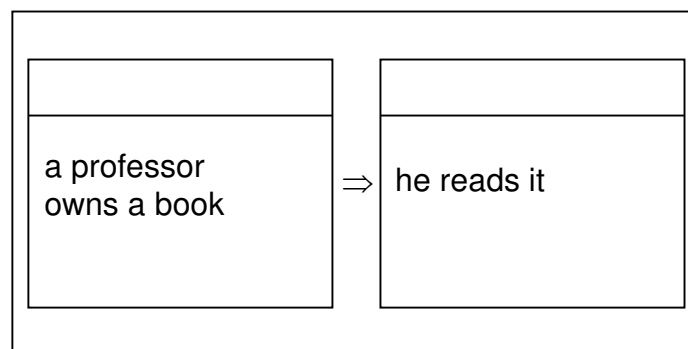
- *A car is parked in front of Peter's garage. Peter needs to get to the office quickly. He doesn't know who owns the car. He calls the police, and the car is towed away.*
- *Suppose a car is parked in front of Peter's garage. Peter needs to get to the office quickly. He doesn't know who owns the car. 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.

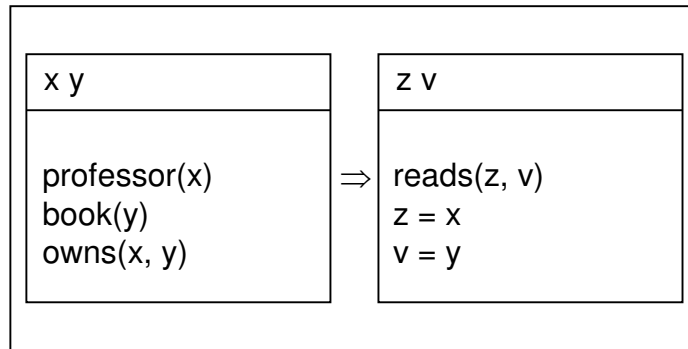
Conditional DRS: An example

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



An example

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



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:
 - $R(u_1, \dots, u_n)$ 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 if [s β] (then) [s γ]]
- Action:
 - Remove α from C_K .
 - Add $K_1 \Rightarrow K_2$ to C_K , where
 - $K_1 = \langle \emptyset, \{ \beta \} \rangle$ and
 - $K_2 = \langle \emptyset, \{ \gamma \} \rangle$
- 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

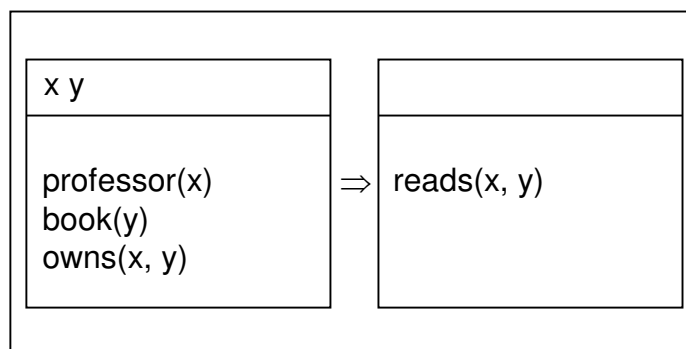
- Let
 - U_D a set of discourse referents,
 - $K = \langle U_K, C_K \rangle$ a DRS with $U_K \subseteq U_D$,
 - $M = \langle U_M, V_M \rangle$ an FOL model structure appropriate for K .
- An *embedding* of K into M is a (partial) function f from U_D to U_M such that $U_K \subseteq \text{Dom}(f)$.

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 ($f \models_M \alpha$):
 - $f \models_M R(x_1, \dots, x_n)$ iff $\langle f(x_1), \dots, f(x_n) \rangle \in V_M(R)$
 - $f \models_M x = a$ iff $f(x) = V_M(a)$
 - $f \models_M x = y$ iff $f(x) = f(y)$
 - $f \models_M K_1 \Rightarrow K_2$ iff
 for all $g \supseteq f$ s.t. $\text{Dom}(g) = \text{Dom}(f) \cup U_{K_1}$
 and $g \models_M K_1$, we also have $g \models_M K_2$

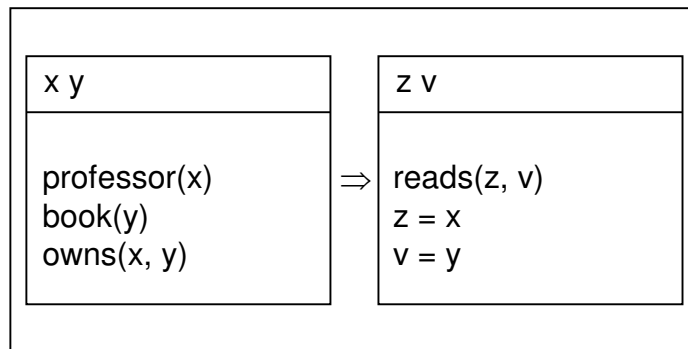
The definition seems to work ...

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



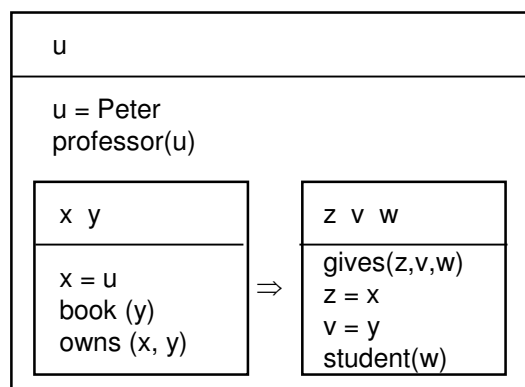
... but it doesn't really!

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



A more complex example

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



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 $\text{Dom}(f) = \text{Dom}(g) \cup U$ "
- $f \supseteq_{\{x_1, \dots, x_n\}} g$ for
" $f \supseteq g$ and $\text{Dom}(f) = \text{Dom}(g) \cup \{x_1, \dots, x_n\}$ "
- $f \supseteq_x g$ 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 :

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

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

(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

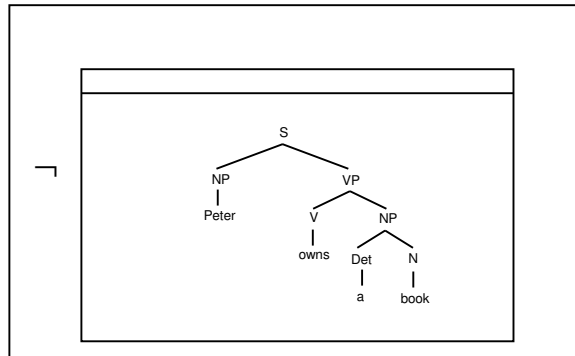
- Triggering configuration:
 - α is a reducible condition in DRS K ; α contains a subtree $[_S [_{NP} \beta] [_{VP} \gamma]]$ or $[_{VP} [_V \gamma] [_{NP} \beta]]$
 - $\beta = \text{every } \delta$
- Action:
 - Remove α from C_K .
 - Add $K_1 \Rightarrow K_2$ to C_K , where
 - $K_1 = \langle \{x\},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

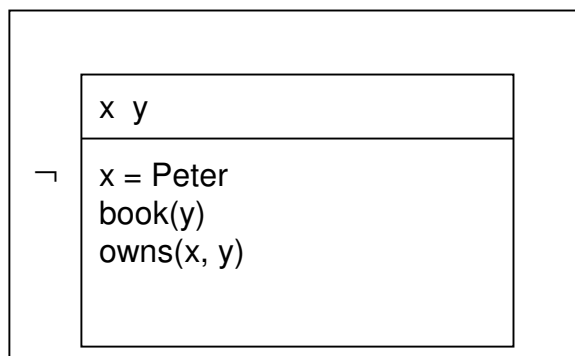
An example

- *Peter doesn't own a book.*



An example

- *Peter doesn't own a book.*

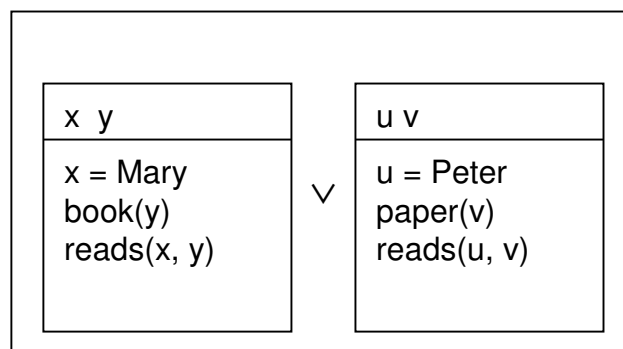


DRS construction rule for sentence disjunction

- 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.



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:
 - $R(u_1, \dots, u_n)$ 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

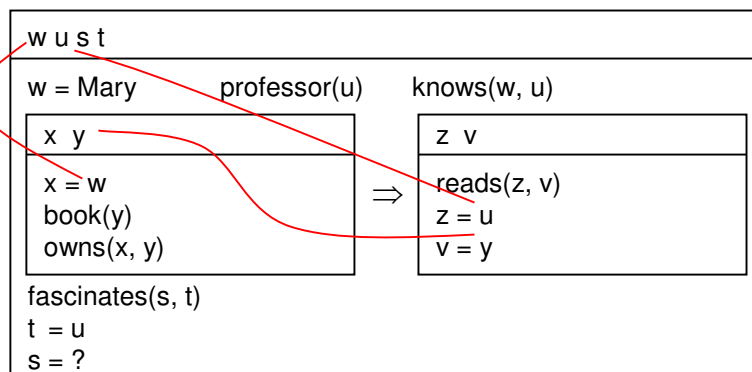
- f verifies condition α in M ($f \models_M \alpha$):
 - $f \models_M R(x_1, \dots, x_n)$ iff $\langle f(x_1), \dots, f(x_n) \rangle \in V_M(R)$
 - $f \models_M x = a$ iff $f(x) = V_M(a)$
 - $f \models_M x = y$ iff $f(x) = f(y)$
 - $f \models_M K_1 \Rightarrow K_2$ iff for all $g \supseteq_{U_{K_1}} f$ s.t. $g \models_M K_1$ there is a $h \supseteq_{U_{K_2}} g$ s.t. $h \models_M K_2$
 - $f \models_M \neg K_1$ iff there is no $g \supseteq_{U_{K_1}} f$ s.t. $g \models_M K_1$
 - $f \models_M K_1 \vee K_2$ 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
 $T(\langle\{u_1, \dots, u_n\}, \{c_1, \dots, c_n\}\rangle) = \exists u_1 \dots \exists u_n [T(c_1) \wedge \dots \wedge T(c_n)]$
- Conditions:
 - $T(c) = c$ (c atomic condition)
 - $T(\neg K_1) = \neg T(K_1)$
 - $T(K_1 \vee K_2) = T(K_1) \vee T(K_2)$
 - $T(K_1 \Rightarrow K_2) = \forall u_1 \dots \forall u_n [T(c_1) \wedge \dots \wedge T(c_n) \Rightarrow T(K_2)],$
 if $K_1 = \langle\{u_1, \dots, u_n\}, \{c_1, \dots, c_n\}\rangle$
- 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.

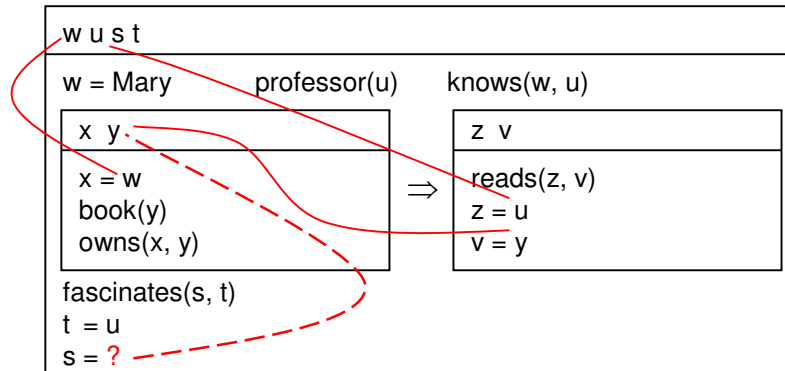
Anaphora and accessibility

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



Anaphora and accessibility

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



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 $x = \beta$ 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.

Anaphora resolution: Pronoun anaphora

- "Hard" linguistic criteria: Constraints
- "Soft" linguistic criteria: Preferences
- Non-linguistic criteria: Plausibility

"Hard" linguistic criteria [1]

- Binding principles:
 - *Peter_i knows that John_j knows him_{i/*j}.*
 - *Peter_i knows that John_j knows himself_{*i/j}.*
 - *He_{*i/*j} knows that John_i knows Peter_j.*
- Agreement:
 - Gender, number, ...

"Hard" linguistic criteria [2]

- Selectional restrictions:
 - *The monkey ate the banana because it was hungry.*
 - *The monkey ate the banana because it was ripe.*
- Accessibility:
 - *? If a professor doesn't own every book, he buys it.*
 - But: Inaccessible discourse referents can be made accessible by "accommodation":
It is not true that Peter doesn't own a car. It is parked outside.

"Soft" linguistic criteria [1]

- Recency:
 - *Peter_i watched a movie. John_j read a book.
He_{i>j} liked it.*
- Parallelism of word order, case, thematic role:
 - *John_i knows Peter_j, and he_i likes him_j.*
- Contrast:
 - *John_i likes Peter_j, and HE_j likes HIM_i.*

"Soft" linguistic criteria [2]

- Many other phenomena have an influence on anaphoric resolution preferences, e.g.
 - NP type of the antecedent (demonstrative vs. indefinite vs. definite)
 - discourse structure
- See e.g. Centering Theory
 - B. Grosz, A. Joshi, S. Weinstein, „Centering: A framework for modelling the local coherence of discourse“, Computational Linguistics 21, 203-225

Non-linguistic criteria [1]

- Practical plausibility: World knowledge
 - *A friend_i sold his car to Peter_j.*
Now he_{ij??} has a lot of money.
 - *A friend_i sold his car to Peter_j.*
Now he_{i??/j} is really poor.

Non-linguistic criteria [2]

- Communicative plausibility: e.g. informativity
 - *Peter's wife_i has a friend_j. She_{i??/j} is unmarried.*
 - *Peter's wife_i has a friend_j. She_{i??/j} is married.*
 - *Mary_i has a married friend_j. She_{i/j??} is married.*
- Communicative plausibility can be explained via the Gricean Maxims: The listener of an utterance may assume that it was intended as informative.

Interactions between the different levels

- *Peter loves his dog, although he sometimes bites him.*
 - Linguistic criteria: faster than world knowledge
 - Linguistic constraints stronger than world knowledge
 - World knowledge stronger than preferences

Summary

- DRT can be extended to deal with complex logical structures of a discourse (if-then, negation, ...)
- Can define accessibility for anaphoric reference based on the structure of a DRS
- In real life, anaphora resolution is a process that is governed by many factors beyond pure accessibility