Semantic Theory: Discourse Representation Theory II

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Discourse Representation Theory (DRT)

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

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

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

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

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

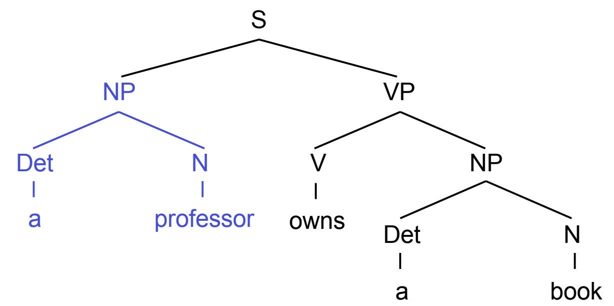
$\downarrow$

Interpretation by model embedding:

Truth conditions of Σ

An example

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

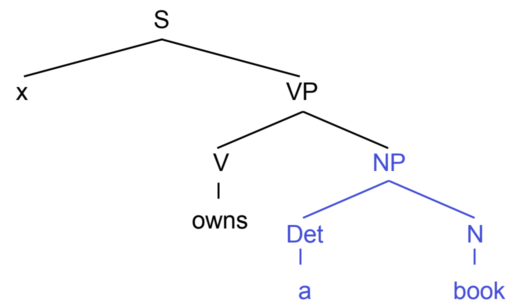


An example

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

x

professor (x)

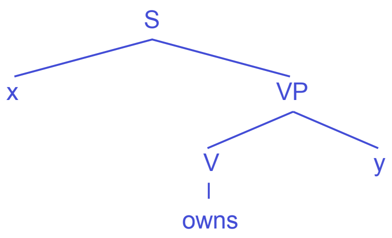


An example

- *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

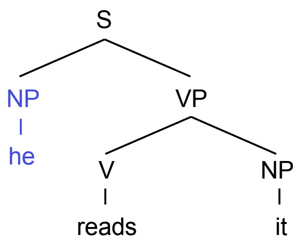
professor(x)
book(y)
own(x, y)

An example

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

x y

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

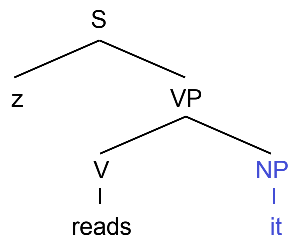


An example

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

x y z

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

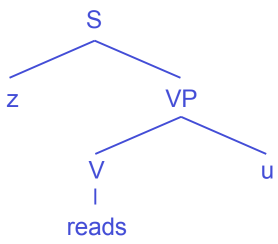


An example

- *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)

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.

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 $f(x) = f(y)$

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 $Dom(f) = U_K$

- 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:

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

Basic features of DRT

- 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.
- DRT models linguistic meaning as anaphoric potential (through DRS construction) plus truth conditions (through model embedding).

DRT II: Extensions

- Conditionals, indefinites and anaphora
- Complex conditions
- Accessibility

Indefinite NPs and conditionals

Indefinite NPs and conditional clauses:

- *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.

Indefinite NPs, Conditionals, and Anaphora

- *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) $\forall x[\text{error}(x) \& \text{occurs}(x) \rightarrow \text{display}(x)]$
- Problem: (1) is not closed; (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.*

Indefinite NPs and Discourse Structure

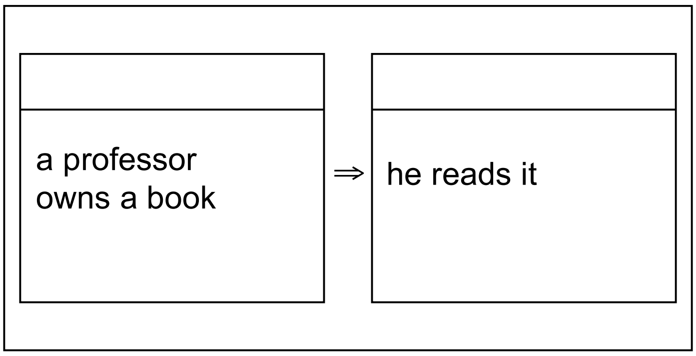
- *A car is parked in front of Peter's garage. Peter needs to get to the office quickly. He doesn't know who owns the car. He calls the police, and it is towed away.*
- *Suppose a car is parked in front of Peter's garage. Peter needs to get to the office quickly. He doesn't know who owns the car. Then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

- The „quantificational force“ of indefinites depends on context:
  - Existential in plain assertions and narrative contexts
  - Universal in conditional or hypothetical reasoning.
- DRT offers uniform treatment in DRS construction, different truth conditional interpretation induced is by the respective context.

DRS for conditionals: An example

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



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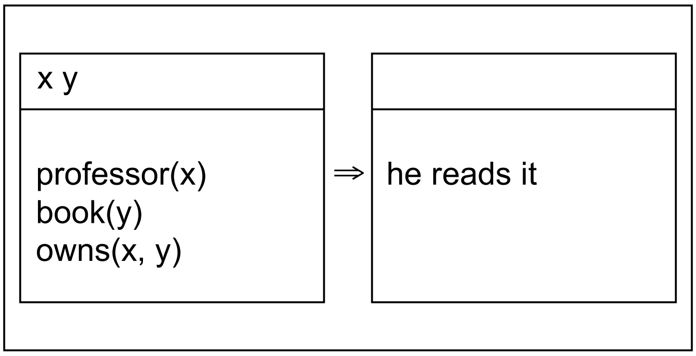

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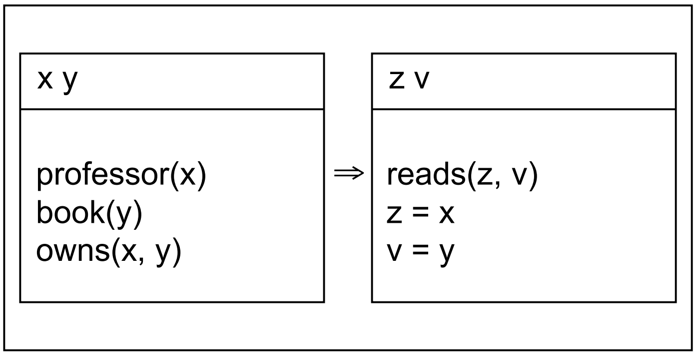


DRS (1st Extension)

- 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 DRSes
- 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
    - $K_1 = \langle \emptyset, \{ \beta \} \rangle$ and
    - $K_2 = \langle \emptyset, \{ \gamma \} \rangle$
- Remark: $K_1 \Rightarrow K_2$ is called a duplex condition; K_1 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 (1st extension, 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 $g \models_M K_2$

Notation: Extending embeddings

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

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

We write

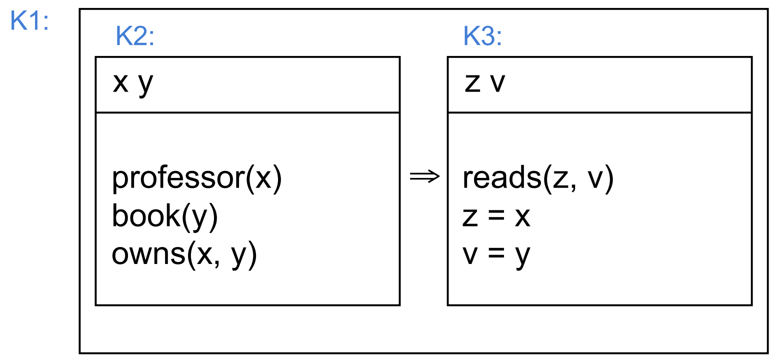
- $f \supseteq_U g$ for "$f \supseteq g$ and $Dom(f) = Dom(g) \cup U$"
- $f \supseteq_{\{x1, ..., xn\}} g$ for "$f \supseteq g$ and $Dom(f) = Dom(g) \cup \{x_1, ..., x_n\}$"
- $f \supseteq_x g$ for "$f \supseteq_{\{x\}} g$".

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 $g \models_M K_2$

The definition seems to work ...

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



... but it doesn't really!

A slightly 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)	⇒	gives(z,v,w) z = x v = y student(w)

Verifying embeddings for conditionals (final)

- An embedding f of K into M verifies K in M:
  f $|=_M$ K iff f verifies every condition $\alpha \in C_K$.
- f verifies condition α in M (f $|=_M \alpha$):
  (i) f $|=_M R(x_1,\ldots, x_n)$ iff $\langle f(x_1), \ldots , f(x_n)\rangle \in V_M(R)$
  (ii) f $|=_M$ x = a iff $f(x) = V_M(a)$
  (iii) f $|=_M$ x = y iff f(x) = f(y)
  (iv) f $|=_M K_1 \Rightarrow K_2$ iff for all g $\supseteq_{U_{K_1}}$ f s.t. g $|=_M K_1$ there is a h $\supseteq_{U_{K_2}}$ g s.t. h $|=_M K_2$

DRS construction rule for universal NPs

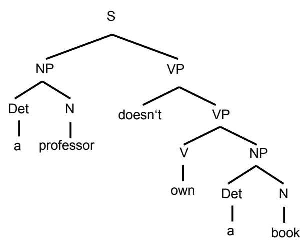
- Triggering configuration:
  - α is a reducible condition in DRS K; α contains a subtree $[_S [_{NP}\ \beta]\ [_{VP}\ \gamma]]$ or $[_{VP} [_V\ \gamma]\ [_{NP}\ \beta]]$
  - β = every δ
- Action:
  - Remove α from C_K.
  - Add $K_1 \Rightarrow K_2$ to C_K, where
    - $K_1 = \langle\{x\}, \{\delta(x)\}\rangle$ 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 $[_S\ \beta\ [_{VP}$ doesn't $[_{VP}\ \gamma]]]$
- Action:
  - Remove α from C_K .
  - Add $\neg K_1$ to C_K, where $K_1 = \langle\varnothing, \{[_S\ \beta\ [_{VP}\ \gamma]]\}\rangle$,

Example

- *A professor doesn't own a book.*

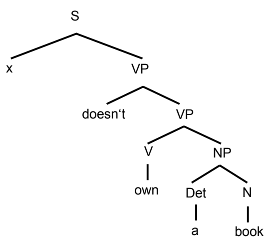


Example

- *A professor doesn't own a book.*

x

professor (x)



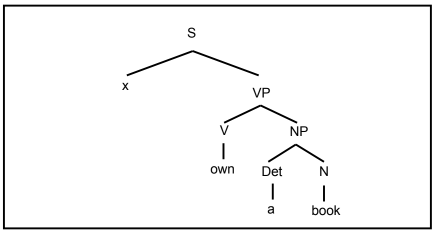
Example

- *A professor doesn't own a book.*

x

professor (x)

¬



Example

- *A professor doesn't own a book.*

x

professor (x)

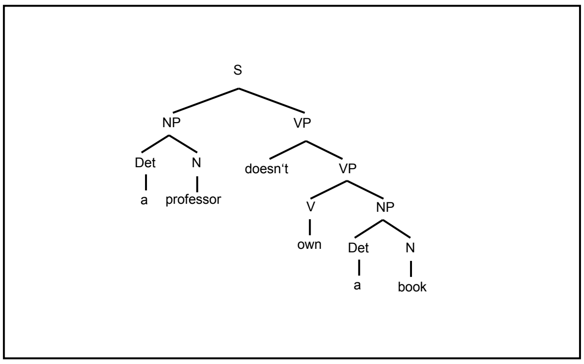
¬

y

book(y)
owns(x, y)

Example: A second reading

- *A professor doesn't own a book.*



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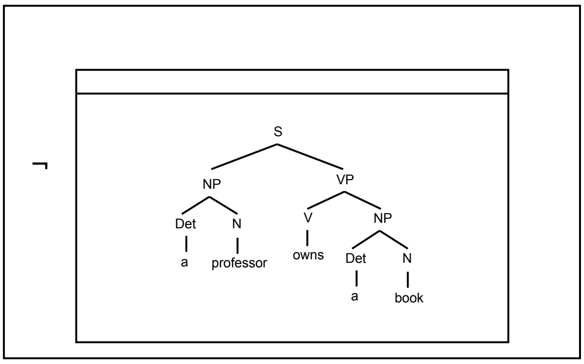

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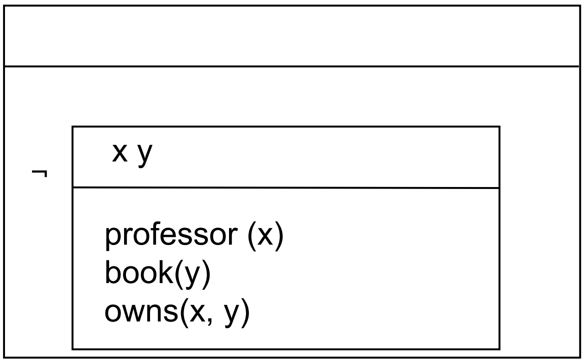


DRS construction rule for clausal disjunction

- 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

- *A student reads a book, or a professor reads a paper.*

x y		u v
student(x) book(y) reads(x, y)	v	professor(u) paper(v) reads(u, v)

DRS (2nd 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:
  - $R(u_1, . . . , u_n)$ — 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:

  $T(c) = c$ for atomic conditions c

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

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

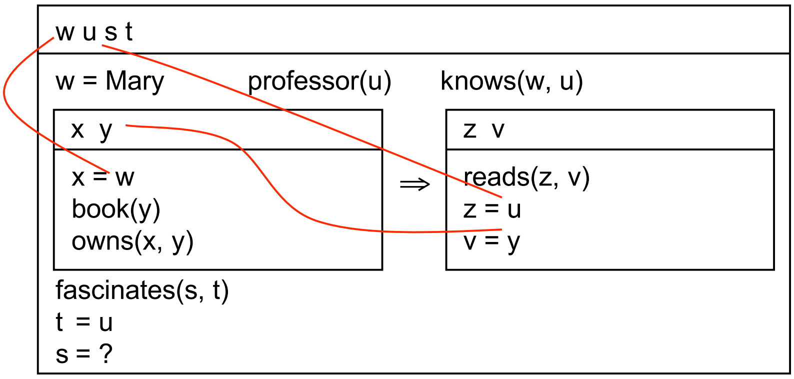
  $T(K_1 \Rightarrow K_2) = \forall u_1 \ldots \forall u_n[(T(c_1) \wedge \ldots \wedge T(c_n)) \rightarrow T(K_2)]$,

  for $K_1 = \langle\{u_1, \ldots , u_n\}, \{c_1, \ldots , c_n\}\rangle$

- 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.

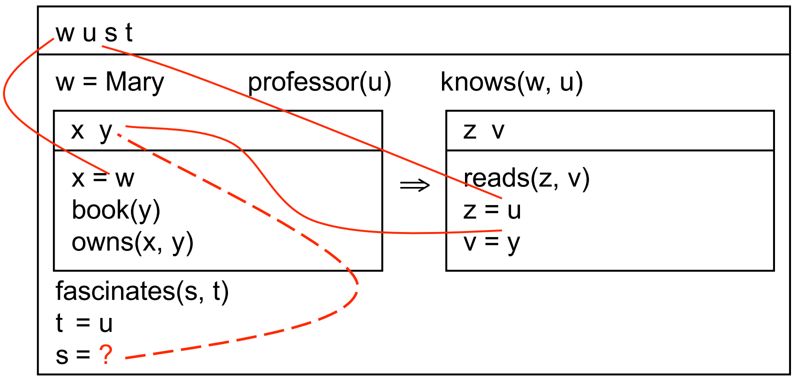
Anaphora and accessibility

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



Anaphora and accessibility

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



Accessible discourse referents

- The following discourse referents are accessible for a condition:
  - DRs in the same local DRS
  - DRs in a superordinate DRS
  - DRs on the top level of an antecedent DRS, if the condition occurs in 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 $K_2 \leq K_3$

Revised DRS Construction rules for NPs

- Triggering Configuration:
  - Let K* be the main DRS that containing K
  - α a reducible condition in DRS K, containing $[_S [_{NP}\ \beta]\ [_{VP}\ \gamma]]$ or $[_{VP} [_V\ \gamma]\ [_{NP}\ \beta]]$ as substructure
  - β a personal pronoun.
- 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:
  - Let K* be the main DRS that containing K
  - α a reducible condition in DRS K, containing $[_S [_{NP}\ \beta]\ [_{VP}\ \gamma]]$ or $[_{VP} [_V\ \gamma]\ [_{NP}\ \beta]]$ as substructure.
  - β a proper name
- 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?

- *There is a book that John doesn‘t own.*
  He wants to buy it.
- *John does not own every book.*
  ?He wants to buy it.
- *One of the ten balls is not in the bag.*
  It must be under the sofa.
- *? Nine of the ten balls are in the bag.*
  It must be under the sofa.

DRT is non-compositional

- DRT is non-compositional on truth conditions: The different discourse-semantic status of the text pairs is not predictable through the (identical) truth conditions of its component sentences.
- Since structural information which cannot be reduced to truth conditions is required to compute the semantic value of texts, DRt is called a representational theory of meaning.

Wait a minute …

- Why can't we just marry type theoretic semantics with DRT?
- Use λ-abstraction and reduction a we did before, but:
- Assume that the target representations which we want to arrive at are not First-Order Logic formulas, but DRSes.
- The result is called naïve λ-DRT.

λ-DRSes

- *every student* ⇒ λG [[z | student(z)] ⇒ G(x)]

z
student(z)

⇒ G(x)

alternative notation: λG [∅ | [z | student(z)] ⇒ G(z)]

- *works* ⇒ λx [∅ | work(x)]

An expression consists of a lambda prefix and a (partially instantiated) DRS.

λ-DRT: β-reduction

- *every student works*

  ⇒ λG[∅ | [z | student(z)] ⇒ G(z)]](λx.[∅ | work(x)])

  ⇔ [∅ | [z | student(z)] ⇒ λx.[∅ | work(x)](z)]

  ⇔ [∅ | [z | student(z)] ⇒ [∅ | work(z)]]

λ -DRT: The "Merge" operation

- *a student* ⇒ λG ([z | student(z)]; G(z))
- *works* ⇒ λx [∅ | work(x)]

- *A student works*

  ⇒ λG ([z | student(z)];G(z))(λx.[∅ | work(x)])
  ⇔ [z | student(z)]; λx.[∅ | work(x)](z)
  ⇔ [z | student(z)]; [∅ | work(z)]
  ⇔ [z | student(z), work(z)]

Merge

- The "merge" operation on DRSs combines two DRSs (conditions and universes).
- It has a function which is comparable to beta reduction: Replace a complex formula (the ";"-combination of two DRSs) by an equivalent simpler formula.
- It is also similar to DPL conjunction.
- Let $K_1 = [\, U_1 \mid C_1 \,]$ and $K_2 = [\, U_2 \mid C_2 \,]$.

  Then: $K_1; K_2 \Rightarrow [\, U_1 \cup U_2 \mid C_1 \cup C_2 \,]$

  under the assumption that no discourse referent $u \in U_2$ occurs free in a condition $\gamma \in C_1$.

λ-DRT and Merge: An example

- *A student works. She is successful.*
- Compositional analysis:
- λK λK'(K;K')([z | student(z), work(z)])([|successful(z)])

  ⇔ λK'([z | student(z), work(z)];K')([|successful(z)])

  ⇔ [z | student(z), work(z)];[|successful(z)]

  ⇔ [z | student(z), work(z), successful(z)]

Why is this naïve?

λK'([z | student(z), work(z)];K')([|successful(z)])

⇔ [z | student(z), work(z)];[|successful(z)]

⇔ [z | student(z), work(z), successful(z)]

- Via the interaction of β-reduction and DRS-binding, discourse referents are captured.
- But the β-reduced DRS must still be equivalent to the original DRS!
- This means that we somehow have to encode the potential for capturing discourse referents into the denotation of a λ-DRS. Getting this right is tricky.

Solutions

- Compositional DRT (R. Muskens)
- Dynamic Lambda Calculus (M. Kohlhase/ S. Kuschert/ M. Pinkal)

Higher-order DRT: The challenge

- Via the interaction of β-reduction and DRS-binding, discourse referents are captured.
- But the β-reduced DRS must still be equivalent to the original DRS!
- This means that we somehow have to encode the potential for capturing discourse referents into the denotation of a λ-DRS. Getting this right is tricky.
- Discourse referents and bound variables behave differently! (Discourse referents may be captured.)