Semantic Theory: Discourse Semantics II

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Discourse Representation Theory (DRT)

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

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

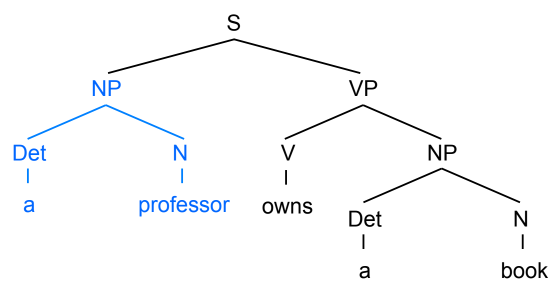
DRS construction $K_0 \rightarrow K_1 \rightarrow K_2 \rightarrow \ldots \rightarrow K_n$

Interpretation by model embedding:

Truth conditions of $\sum$

An example

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



An example

- *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)

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) $f \models_M R(x_1,\ldots, x_n)$ 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 $f(x) = f(y)$

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:

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

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 $Dom(f) = U_K$

Translation of DRSes to FOL

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

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

is truth-conditionally equivalent to the following FOL formula:

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

Indefinite NPs and conditionals

- *If a student works, the professor is happy.*

(1) $\exists x[\text{student}(x) \wedge \text{work}(x)] \rightarrow \text{happy\_prof}$
(2) $\forall x[\text{student}(x) \wedge \text{work}(x) \rightarrow \text{happy\_prof}]$

- Formulas (1) and (2) are logically equivalent:
  $\exists xA \rightarrow B \;\Leftrightarrow\; \forall x[A \rightarrow B]$
  given that x doesn't occur free in B.

Indefinite NPs, Conditionals, and Anaphora

- *If a student works, she will be successful.*
  (1) $\exists x[\text{student}(x) \wedge \text{work}(x)] \rightarrow \text{successful}(x)$
  (2) $\exists x[\text{student}(x) \wedge \text{work}(x) \rightarrow \text{successful}(x)]$
  (3) $\forall x\,[\text{student}(x) \wedge \text{work}(x) \rightarrow \text{successful}(x)]$

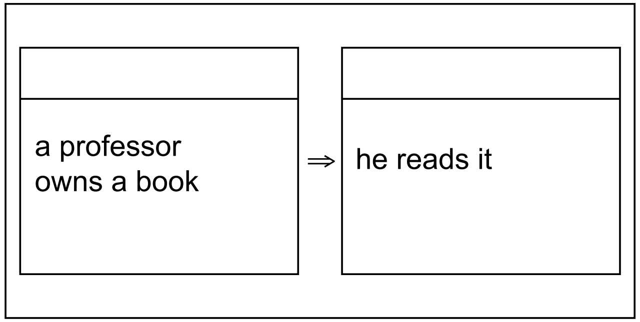
  (1) is not closed
  (2) has wrong truth conditions (much too weak)
  (3) is correct, but how can it be derived compositionally?
- This is called the donkey sentence problem, after the classical example by P.T. Geach (1967):
  If a farmer owns a donkey, he beats it.

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.*

DRS for conditionals: An example

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



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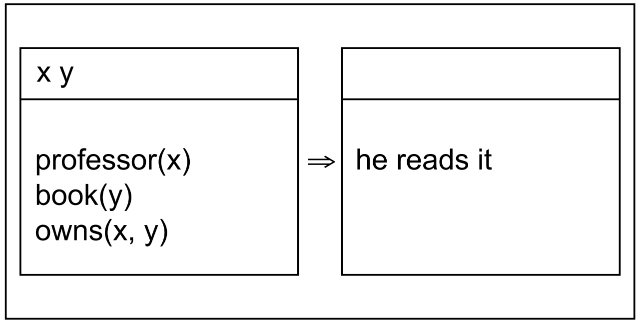

DRS for conditionals: An example

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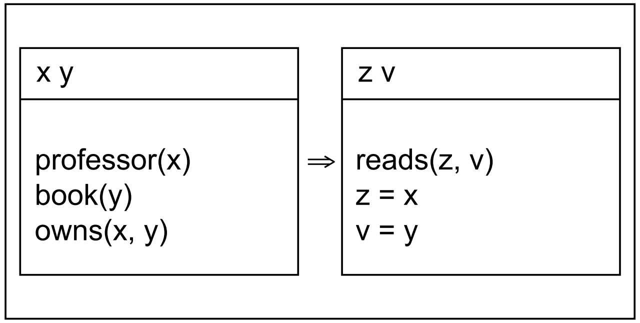


DRS (1st Extension)

- 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
    - $K_1 = \langle \varnothing, \{ \beta \} \rangle$ and
    - $K_2 = \langle \varnothing, \{ \gamma \} \rangle$
- 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 $U_K \subseteq \text{Dom}(f)$.

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) $f \models_M R(x_1,\dots, x_n)$ 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. $g \models_M K_1$, we have $g \models_M K_2$

- We write $g \supseteq_U f$ for "$g \supseteq f$ and $\text{Dom}(g) = \text{Dom}(f) \cup U$"

The definition seems to work ...

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

K0:

K1:		K2:
x y		z v
professor(x) book(y) owns(x, y)	$\Rightarrow$	reads(z, v) z = x v = y

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

... but it doesn't really!

A slightly more complex example:

- *Mary knows a professor.*
  If he owns a book, he gives it to a student.

s u		
s = Mary professor(u) know(s, u)		
x y ——— x = u book (y) owns (x, y)	$\Rightarrow$	z v w ——— 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

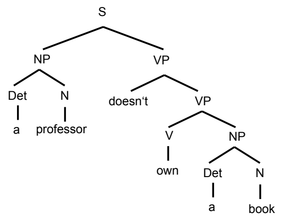
- Triggering configuration:
  - α is a reducible condition in DRS K; α contains a subtree $[_S [_{NP}\ \beta]\ [_{VP}\ \gamma]]$ or $[_{VP} [_V\ \gamma]\ [_{NP}\ \beta]]$
  - β = every δ
- Action:
  - Remove α from C_K.
  - Add $K_1 \Rightarrow K_2$ to C_K, where
    - $K_1 = \langle\{x\}, \{\delta(x)\}\rangle$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

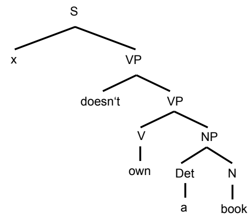


Example

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

x

professor (x)



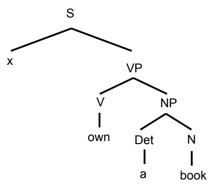
Example

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

x

professor (x)

¬



Example

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

x

professor (x)

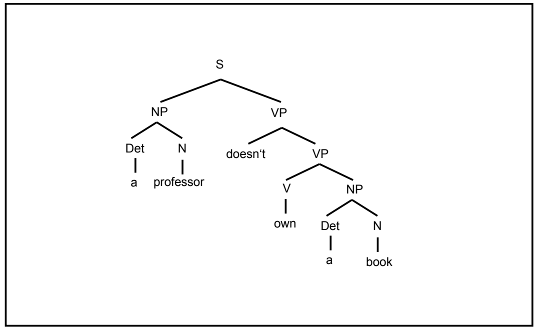
¬

y

book(y)
owns(x, y)

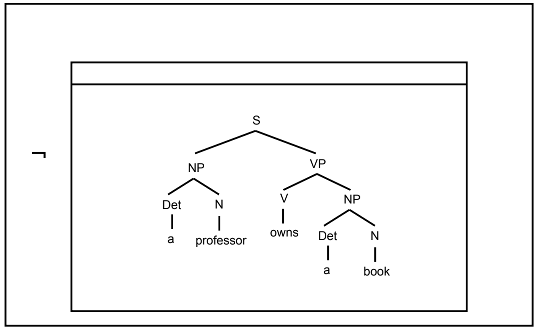
Example: A second reading

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



Example: A second reading

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



Example: A second reading

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

¬

x y

professor (x)
book(y)
owns(x, y)

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
    - $K_1 = \langle\varnothing, \{\beta\}\rangle$ and
    - $K_2 = \langle\varnothing, \{\gamma\}\rangle$

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:
  - $R(u_1, \ldots, u_n)$ — 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 from 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, 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.*

```
w u s t
w = Mary        professor(u)      knows(w, u)
 [ x y           ]        [ z v          ]
 [ x = w         ]   ⇒    [ reads(z, v)  ]
 [ book(y)       ]        [ z = u        ]
 [ owns(x, y)    ]        [ v = y        ]
fascinates(s, t)
t = u
s = ?
```


Anaphora and accessibility

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

```
w u s t
w = Mary        professor(u)      knows(w, u)
 [ x y           ]        [ z v          ]
 [ x = w         ]   ⇒    [ reads(z, v)  ]
 [ book(y)       ]        [ z = u        ]
 [ owns(x, y)    ]        [ v = y        ]
fascinates(s, t)
t = u
s = ?
```


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 reads a book, or Mary reads a newpaper article. It is interesting.*

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.

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 DRSes 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 rule for Pronouns

- Triggering Configuration:
  - Let K* be the main DRS that contains 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 $x = \beta$ 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 λ-DRT.

λ-DRSes

- *every student* ⇒ $\lambda G \boxed{\boxed{\begin{array}{l} z \\ \hline \text{student}(z) \end{array}} \Rightarrow G(x)}$

  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*

$\Rightarrow \lambda G[\, \varnothing \mid [\, z \mid student(z)\,] \Rightarrow G(z)\,]](\lambda x.[\, \varnothing \mid work(x)\,])$

$\Leftrightarrow [\, \varnothing \mid [\, z \mid student(z)\,] \Rightarrow \lambda x.[\, \varnothing \mid work(x)\,](z)\,]$

$\Leftrightarrow [\, \varnothing \mid [\, z \mid student(z)\,] \Rightarrow [\, \varnothing \mid work(z)\,]]$

(Naïve) Merge

- The “merge” operation on DRSs combines two DRSs (conditions and universes).
- Let $K_1 = [\, U_1 \mid C_1\,]$ and $K_2 = [\, U_2 \mid C_2\,]$.
  Then: $K_1; K_2 \Rightarrow [\, U_1 \cup U_2 \mid C_1 \cup C_2\,]$

Merge: An example

- *a student* $\Rightarrow \lambda G\, ([\, z \mid student(z)\,];\, G(z))$
- *works* $\Rightarrow \lambda x\, [\, \varnothing \mid work(x)\,]$

- *A student works*

$\Rightarrow \lambda G\, ([\, z \mid student(z)\,]; G(z))(\lambda x.[\, \varnothing \mid work(x)])$
$\Leftrightarrow [\, z \mid student(z)\,];\, \lambda x.[\, \varnothing \mid work(x)](z)$
$\Leftrightarrow [\, z \mid student(z)\,];\, [\, \varnothing \mid work(z)]$
$\Leftrightarrow [\, z \mid student(z), work(z)]$

λ–DRT and Merge: An example

- *A student works. She is successful.*
- Compositional analysis:
- $\lambda K\, \lambda K'(K;K')([\, z \mid student(z), work(z)])([\ \mid successful(z)])$
  $\Leftrightarrow \lambda K'([z \mid student(z), work(z)];K')([\ \mid successful(z)])$
  $\Leftrightarrow [z \mid student(z), work(z)];[\ \mid successful(z)]$
  $\Leftrightarrow [z \mid student(z), work(z), successful(z)]$

Merge again

- The “merge” operation on DRSs combines two DRSs (conditions and universes).
- Let K_1 = [U_1 | C_1] and K_2 = [U_2 | 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 $\gamma \in C_1$.

Variable capturing

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. Possible, but tricky.

Events and event anaphora in DRT

•*The gardener killed the baron . It happened at midnight.*

e, g, b

gardener(g)
baron(b)
kill(e,g,b)

e, g, b,e'

gardener(g)
baron(b)
kill(e,g,b)
midnight(m)
time(e',m)
e'=e

Tense in DRT

John left, after Peter had arrived

j, e, p, e'

leave(e,j)
$e < e_u$

arrive(e',p)
e'< e

Tense in DRT

I didn't turn off the stove

- Simple past is anaphoric!

John left.

j, e, ***r***
leave(e,j) $e < e_u$ e *o* ***r***