Semantic Theory
Week 9 – Discourse Representation Theory

Noortje Venhuizen

Universität des Saarlandes

Summer 2018

Recap: DRS Syntax

A discourse representation structure (DRS) K is a pair $\langle U_K, C_K \rangle$, where:

- $U_K \subseteq U_D$ and U_D is a set of discourse referents, and
- C_K is a set of well-formed DRS conditions

Well-formed DRS conditions:

	where:	
• $R(u_1, \ldots, u_n)$		R is an n-place relation, $u_i \in U_D$
• $u = v$		$u, v \in U_D$
• $u = a$		$u \in U_D$, a is a constant
• $\neg K_1$		K_1 is a DRS
• $K_1 \Rightarrow K_2$		K_1 and K_2 are DRSs
• $K_1 \vee K_2$		K_1 and K_2 are DRSs

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 = **???**

Non-accessible discourse referents

Cases of non-accessibility:

(1) *If a professor owns a book, he reads it. It has 300 pages.*

(2) *It is not the case that a professor owns a book. He reads it.*

(3) *Every professor owns a book. He reads it.*

(4) *If every professor owns a book, he reads it.*

(5) *Peter owns a book, or Mary reads it.*

(6) *Peter reads a book, or Mary reads a newspaper 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 in the universe of an antecedent DRS, if the condition occurs in the consequent DRS.

We need a formal notion of DRS subordination

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

- $K_1 = K$, or
- K_1 is an immediate sub-DRS of K, or
- there is a DRS K_2 such that $K_1 \leq K_2$ and K_2 is an immediate sub-DRS of K (i.e. reflexive, transitive closure)

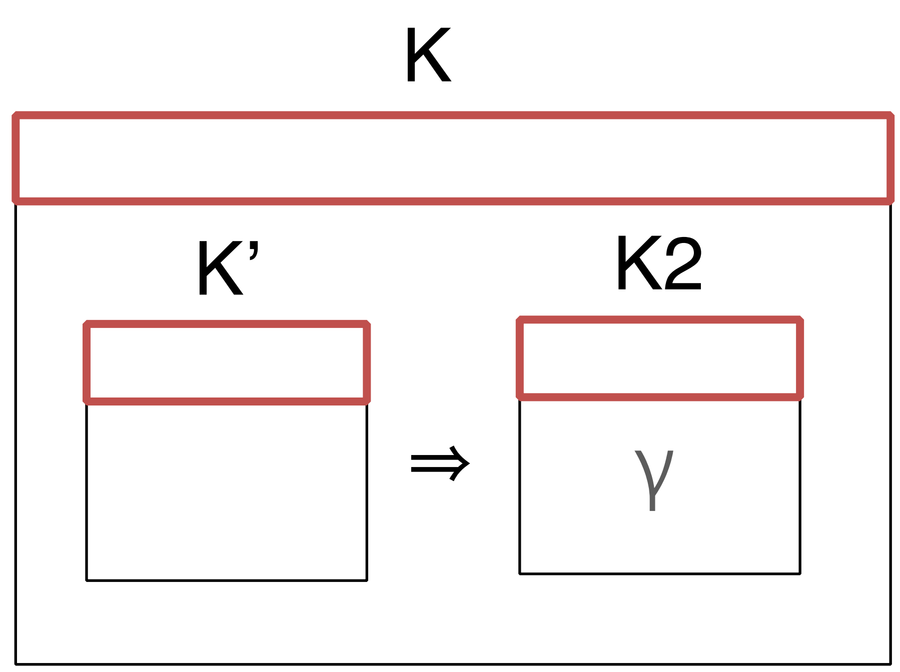
K_1 is a proper sub-DRS of K iff $K_1 \leq K$ and $K_1 \neq K$.

Accessibility

Let K, K_1, K_2 be DRSs such that $K_1, K_2 \leq K$, $x \in U_{K_1}$, $\gamma \in C_{K_2}$

x is accessible from γ in K iff

- $K_2 \leq K_1$ or
- there are $K_3, K_4 \leq K$ such that $K_1 \Rightarrow K_3 \in C_{K4}$ and $K_2 \leq K_3$



Free and bound variables in DRT

A DRS variable x, introduced in DRS K_1, is bound in global DRS K iff there exists a DRS $K_j \leq K$, such that:

(i) $K_i \leq K_j$;

(ii) $x \in U(K_j)$.

Properness: A DRS is *proper* iff it does not contain any free variables

Purity: A DRS is *pure* iff it does not contain any *otiose declarations* of variables

$x \in U(K_1)$ and $x \in U(K_2)$ and $K_1 \leq K_2$

From text to DRS

$$
\begin{tikzcd}
\text{Text} & \Sigma = \langle\ S_1, \arrow[d] & S_2, \arrow[d] & \ldots, & S_n\ \rangle \arrow[d] \\
\text{Syntactic Analysis} & P(S_1) \arrow[d] & P(S_2) \arrow[d] & \ldots & P(S_n) \arrow[d] \\
\text{DRS Construction} & K_1 \arrow[r] & K_2 \arrow[r] & \ldots \arrow[r] & K_n
\end{tikzcd}
$$

DRS Construction Algorithm

Let the following be a well-formed, *reducible* DRS condition:

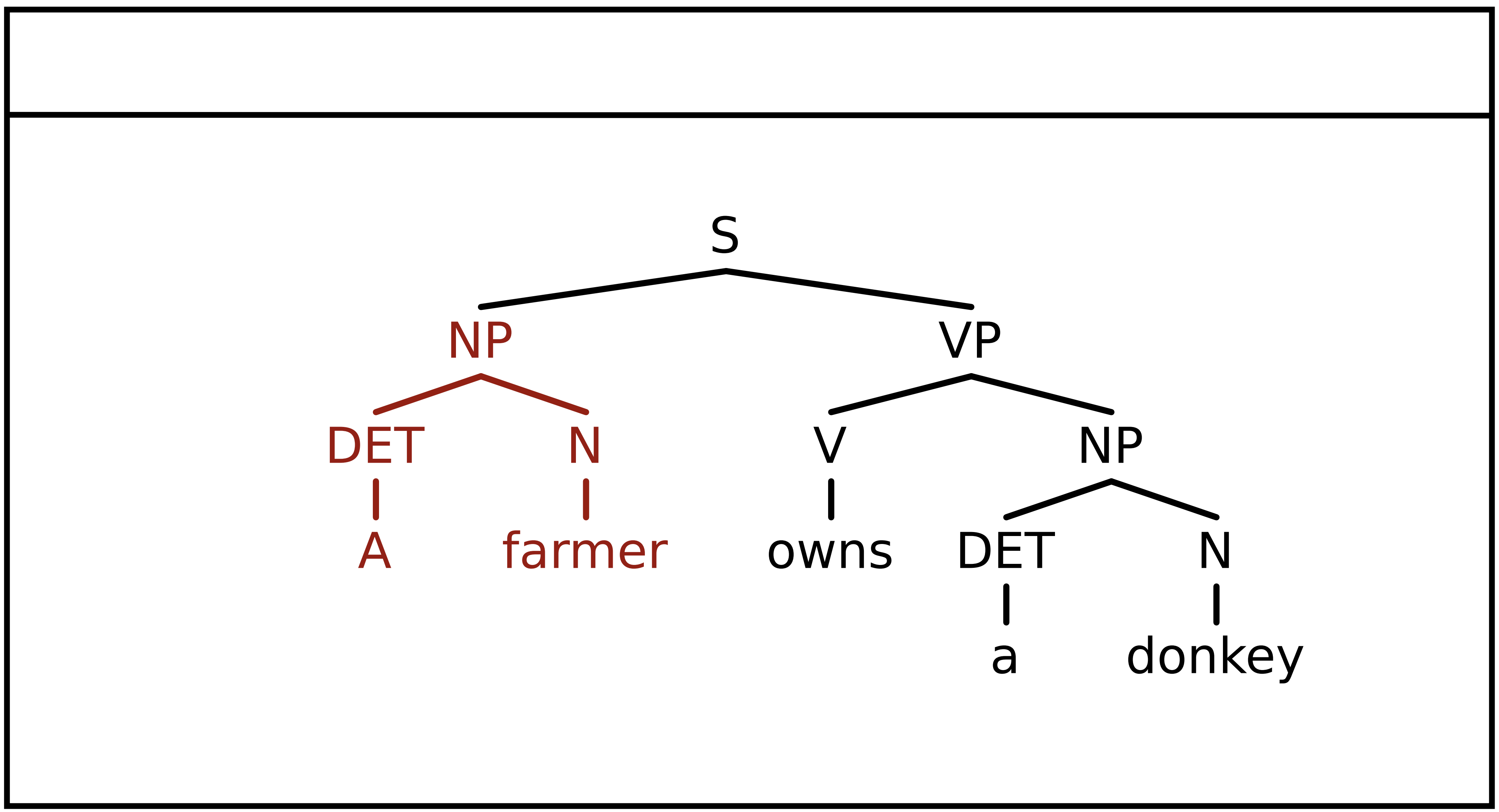
- Conditions of form α or α(x1, …, xn), where α is a context-free parse tree.

DRS construction algorithm:

- Given a text $\Sigma = \langle S_1, \ldots, S_n \rangle$, and a DRS K_0 ($= \langle \varnothing, \varnothing \rangle$, by default)
- Repeat for $i = 1, \ldots, n$:
  - 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 K_i is the discourse representation of text $\langle S_1, \ldots, S_i \rangle$.

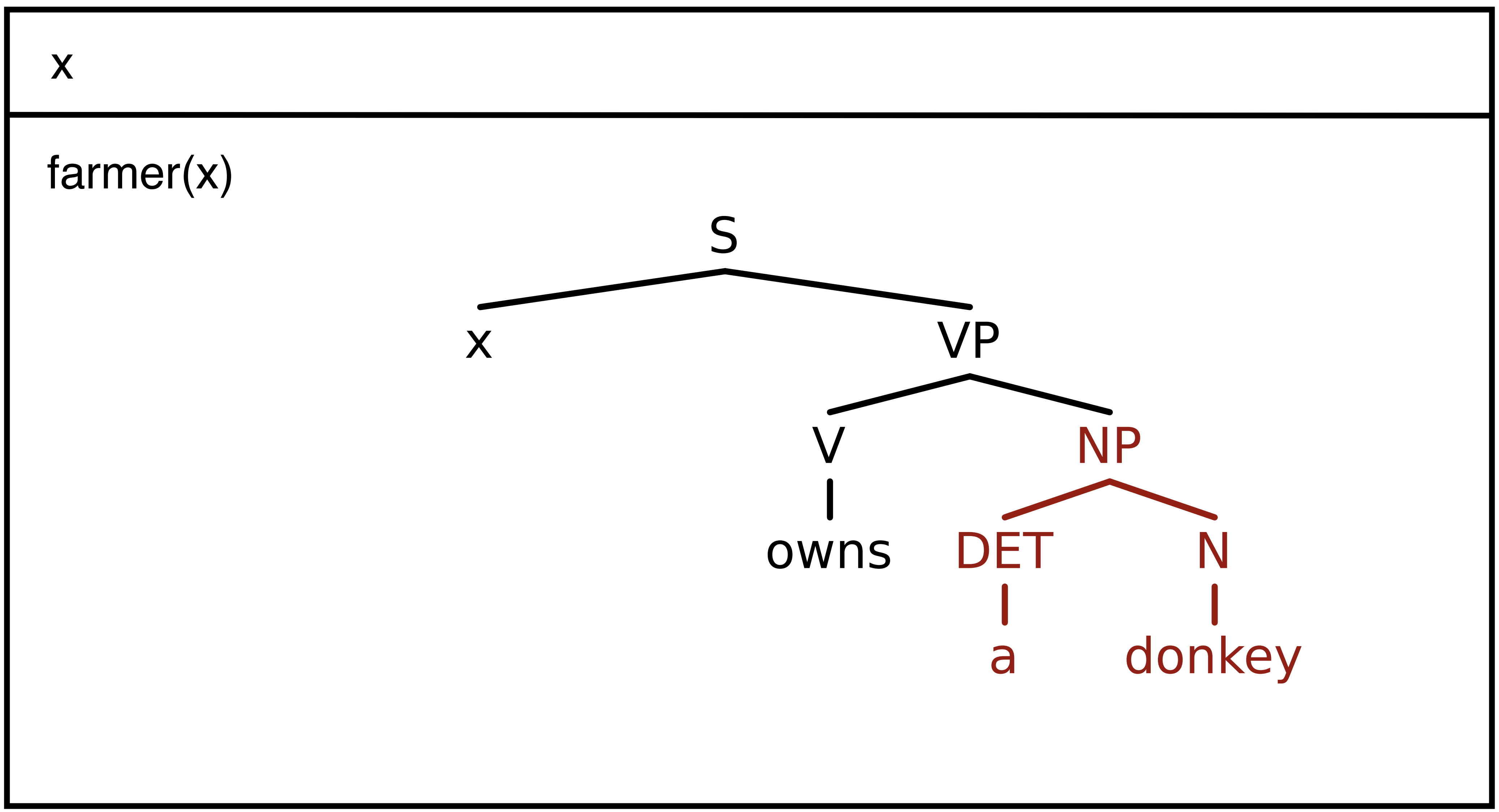
DRS Construction Example

- A farmer owns a donkey. He beats it.



DRS Construction Example

- A farmer owns a donkey. He beats it.



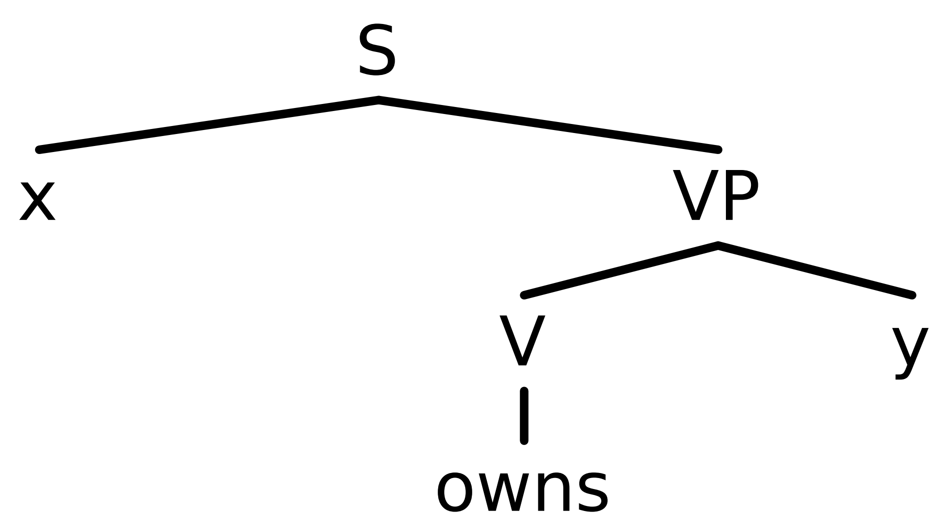
DRS Construction Example

- A farmer owns a donkey. He beats it.

x y

farmer(x)

donkey(y)



DRS Construction Example

- A farmer owns a donkey. He beats it.

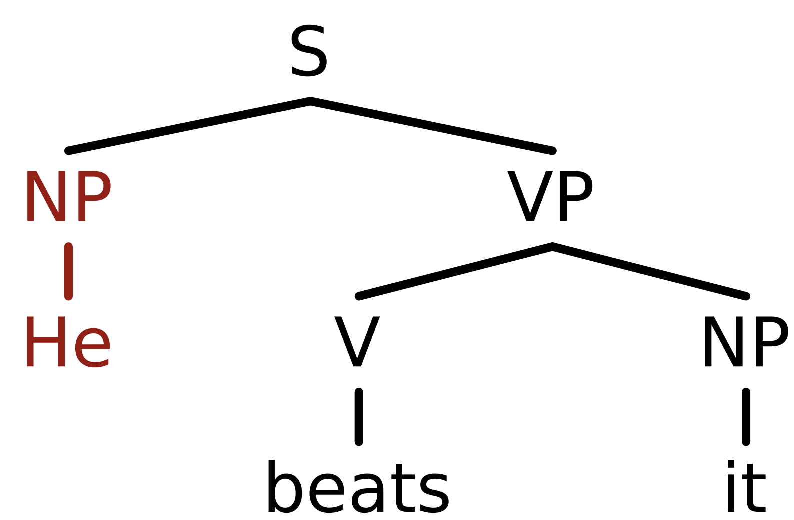
x y
farmer(x) donkey(y) owns(x, y)

DRS Construction Example

- A farmer owns a donkey. He beats it.

x y

farmer(x)
donkey(y)
owns(x, y)



DRS Construction Example

- A farmer owns a donkey. He beats it.

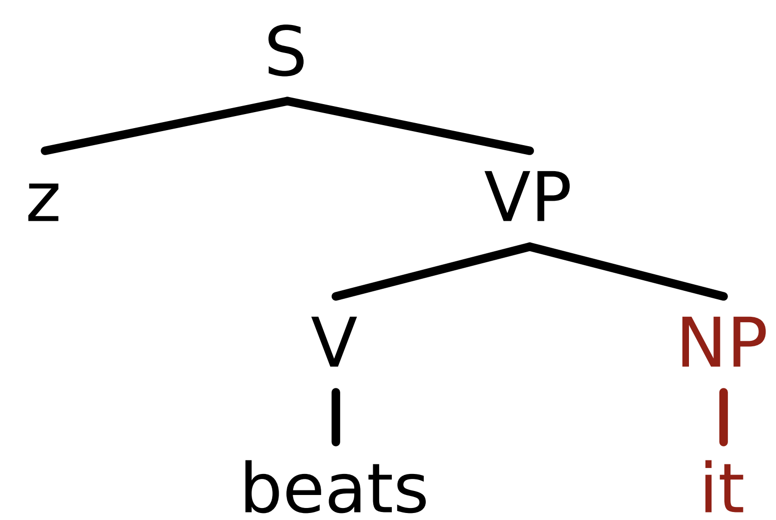
x y z

farmer(x)

donkey(y)

owns(x, y)

z = x



DRS Construction Example

- A farmer owns a donkey. He beats it.

x y z u

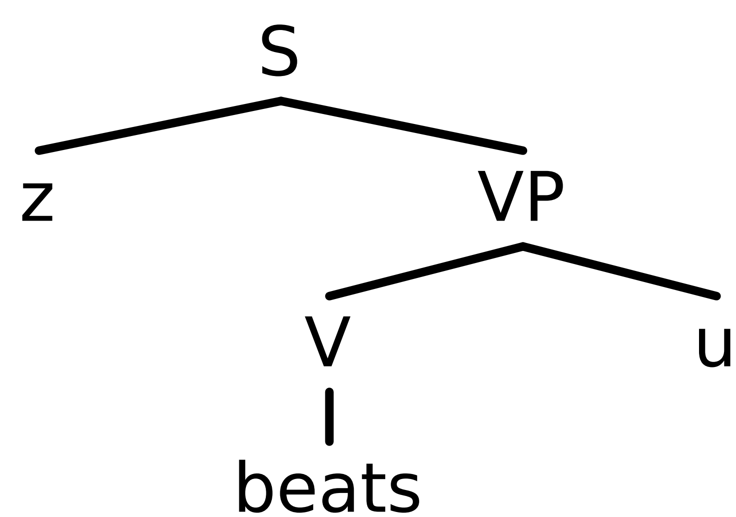
farmer(x)

donkey(y)

owns(x, y)

z = x

u = y



DRS Construction Example

- A farmer owns a donkey. He beats it.

x y z u
farmer(x) donkey(y) owns(x, y) z = x u = y beat(z, u)

Construction Rules: Examples

Indefinite NPs

- **Trigger:** a reducible condition α in DRS K that has a substructure [NP β], such that β is εδ, where ε is an indefinite article
- **Action:** Add new DR x to U_K; Replace β in α by x; Add δ(x) to C_K

Personal Pronouns

- **Trigger:** a global DRS K*, and some K ≤ K*, with a reducible condition α in K that has substructure [NP β], such that 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 that is accessible from α in K*; Add x = y to C_K

A constraint on DRS construction

Problem: The basic DRS construction algorithm can derive DRSs for both of the following sentences, with the indicated anaphoric binding:

(1) [A professor]$_i$ recommends a book that she$_i$ likes

(2) She$_i$ recommends a book that [a professor]$_i$ likes

Solution: If two different triggering configurations 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.

From text to DRS

$$\begin{tikzcd}
\text{Text} & \Sigma = \langle\ S_1, \arrow[d] & S_2, \arrow[d] & \ldots, & S_n\ \rangle \arrow[d] \\
\text{Syntactic Analysis} & P(S_1) \arrow[d] & P(S_2) \arrow[d] & \ldots & P(S_n) \arrow[d] \\
\text{DRS Construction} & K_1 \arrow[r] & K_2 \arrow[r] & \ldots \arrow[r] & K_n \arrow[d] \\
 & & & & \begin{array}{c}\text{Interpretation by} \\ \text{model embedding:} \\ \text{Truth-conditions of } \Sigma\end{array}
\end{tikzcd}$$

DRS Interpretation

Given a DRS $K = \langle U_K, C_K \rangle$, with $U_K \subseteq U_D$

Let $M = \langle U_M, V_M \rangle$ be a FOL model structure appropriate for K, i.e. a model structure that provides interpretations for all predicates and relations occurring in K

DRS K is *true* in model M *iff*

- there is an embedding function for K in M which verifies all conditions in K

… where: an embedding of K into M is a (partial) function **f** from U_D to U_M such that $U_K \subseteq \mathrm{Dom}(\mathbf{f})$.

Verifying embedding

An embedding **f** of K in M verifies K in M (**f** $\vDash_M$ K) iff **f** verifies every condition $\alpha \in C_K$

- **f** $\vDash_M R(x_1, \ldots, x_n)$ iff $\langle \mathbf{f}(x_1), \ldots, \mathbf{f}(x_n) \rangle \in V_M(R)$
- **f** $\vDash_M x = y$ iff $\mathbf{f}(x) = \mathbf{f}(y)$
- **f** $\vDash_M x = a$ iff $\mathbf{f}(x) = V_M(a)$
- **f** $\vDash_M \neg K_1$ iff there is no **g** $\supseteq_{U_{K1}}$ **f** such that g $\vDash_M K_1$
- **f** $\vDash_M K_1 \Rightarrow K_2$ iff for all **g** $\supseteq_{U_{K1}}$ **f** such that **g** $\vDash_M K_1$

  there is a **h** $\supseteq_{U_{K2}}$ **g** such that **h** $\vDash_M K_2$
- **f** $\vDash_M K_1 \vee K_2$ iff there is a $\mathbf{g_1} \supseteq_{U_{K1}}$ **f** such that $\mathbf{g_1} \vDash_M K_1$
  or there is a $\mathbf{g_2} \supseteq_{U_{K2}}$ **f** such that $\mathbf{g_2} \vDash_M K_2$

Verifying embedding: example

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

$$\boxed{\begin{array}{l} s\ u \\ \hline s = \text{Mary} \qquad \text{professor}(u) \qquad \text{know}(s, u) \\ \boxed{\begin{array}{l} x\ \ y \\ \hline x = u \\ \text{book}\ (y) \\ \text{owns}\ (x, y) \end{array}} \Rightarrow \boxed{\begin{array}{l} z\ \ v\ \ w \\ \hline \text{gives}(z,v,w) \\ z = x \\ v = y \\ \text{student}(w) \end{array}} \end{array}}$$

…is **true** in $M = \langle U_M, V_M \rangle$ *iff* there is an $\mathbf{f} :: U_D \rightarrow U_M$, (with $\{s,u\} \subseteq \text{Dom}(\mathbf{f})$) such that:

$\mathbf{f}(s) = V_M(\text{Mary})$ & $\mathbf{f}(u) \in V_M(\text{prof'})$ & $\langle \mathbf{f}(s), \mathbf{f}(u) \rangle \in V_M(\text{know})$,

and for all $\mathbf{g} \supseteq_{\{x,y\}} \mathbf{f}$ s.t. $\mathbf{g}(x) = \mathbf{g}(u)$ $(=\mathbf{f}(u))$ & $\mathbf{g}(y) \in V_M(\text{book})$ & $\langle \mathbf{g}(x), \mathbf{g}(y) \rangle \in V_M(\text{own})$,

there is a $\mathbf{h} \supseteq_{\{z,\, v,\, w\}} \mathbf{g}$ s.t. $\langle \mathbf{h}(z), \mathbf{h}(v), \mathbf{h}(w) \rangle \in V_M(\text{give})$ & $\mathbf{h}(z) = \mathbf{h}(x)$ $(=\mathbf{g}(x))$ & … etc.

Translation of DRSs to FOL

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

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

K is truth-conditionally equivalent to the following FOL formula:

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

DRT and compositionality

- DRT is non-compositional on truth conditions: The difference in 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.

However…

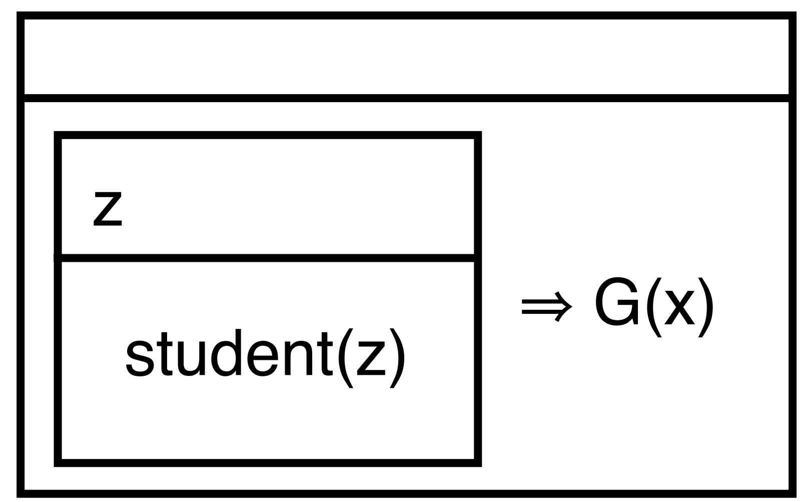
Wait a minute …

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

λ-DRSs

An expression in λ-DRT consists of a lambda prefix and a partially instantiated DRS.

- *every student :: ⟨⟨e, t⟩, t⟩* ↦ λG.



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

- *works :: ⟨e, t⟩* ↦ λx [∅ | work(x)]

λ-DRT: β-reduction

Every student works

$\mapsto \lambda G[\ \varnothing \mid [\ z \mid \text{student}(z)\ ] \Rightarrow G(z)\ ]](\lambda x\ [\ \varnothing \mid \text{work}(x)\ ])$

$\Rightarrow^{\beta} [\ \varnothing \mid [\ z \mid \text{student}(z)\ ] \Rightarrow (\lambda x\ [\ \varnothing \mid \text{work}(x)\ ])(z)\ ]$

$\Rightarrow^{\beta} [\ \varnothing \mid [\ z \mid \text{student}(z)\ ] \Rightarrow [\ \varnothing \mid \text{work}(z)\ ]]$

How do we define conjunction on DRSs?

(Naïve) Merge

The "merge" operation on DRSs combines two DRSs (conditions and universes).

- Let $K_1 = [\ U_1 \mid C_1\ ]$ and $K_2 = [\ U_2 \mid C_2\ ]$.

Merge: $K_1 + K_2 = [\ U_1 \cup U_2 \mid C_1 \cup C_2\ ]$

Merge: An example

- *a student* $\mapsto$ $\lambda G\ ([\ z \mid student(z)\ ] + G(z))$
- *works* $\mapsto$ $\lambda x\ [\ \varnothing \mid work(x)\ ]$

A student works $\mapsto \lambda G\ ([\ z \mid student(z)\ ] + G(z))\ (\lambda x[\ \varnothing \mid work(x)])$

$\Rightarrow^{\beta} [\ z \mid student(z)\ ] + \lambda x[\ \varnothing \mid work(x)](z)$

$\Rightarrow^{\beta} [\ z \mid student(z)\ ] + [\ \varnothing \mid work(z)]$

$\Rightarrow^{\beta} [\ z \mid student(z), work(z)]$

Compositional analysis

- *Mary* $\mapsto$ λG ([z | z = Mary] + G(z))
- she $\mapsto$ $\lambda G.G(z)$

Mary works. She is successful.

$\mapsto$ λK λK'(K + K')([z | z = Mary, work(z)])([|successful(z)])

$\Rightarrow^{\beta}$ λK'([z | z = Mary, work(z)] + K')([|successful(z)])

$\Rightarrow^{\beta}$ [z | z = Mary, work(z)] + ([|successful(z)])

$\Rightarrow^{\beta}$ [z | z = Mary, work(z), successful(z)]

Merge again

The "merge" operation on DRSs combines two DRSs (conditions and universes).

- Let $K_1 = [\ U_1 \mid C_1\ ]$ and $K_2 = [\ U_2 \mid C_2\ ]$.

Merge: $K_1 + K_2 \Rightarrow [\ U_1 \cup U_2 \mid C_1 \cup C_2\ ]$

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

Variable capturing

In λ-DRT, discourse referents are captured via the interaction of β-reduction and DRS-binding:

- $\lambda K'([z \mid student(z), work(z)] + K')([\ \mid successful(z)])$

  $\Rightarrow^{\beta} [z \mid student(z), work(z)] + [\ \mid successful(z)]$

  $\Rightarrow^{\beta} [z \mid student(z), work(z), successful(z)]$

But the β-reduced DRS must still be *equivalent* to the original DRS!

So, the potential for capturing discourse referents must be captured into the interpretation of a λ-DRS. Possible, but tricky.

Literature

Reading:

- Hans Kamp and Uwe Reyle: From Discourse to Logic, Kluwer: Dordrecht 1993.

Link:

- https://plato.stanford.edu/entries/discourse-representation-theory/