Semantic Theory
week 8 – Discourse Representation Theory

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Recap: DRS Syntax

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

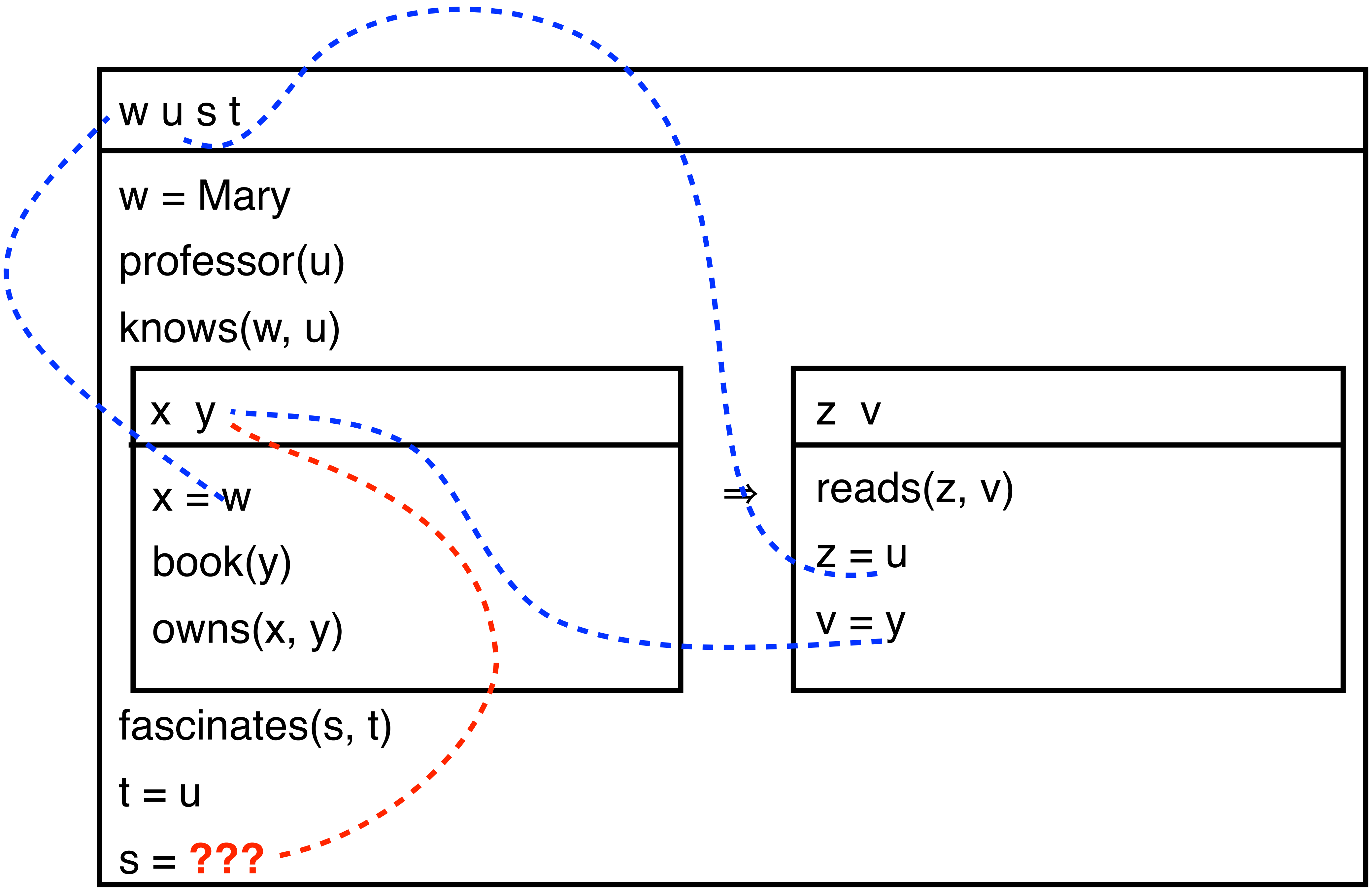
- $U_K \subseteq U_D$ and U_D is a set of discourse referents, and
- C_K is a set of well-formed DRS conditions

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

Recap: Anaphora and accessibility

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

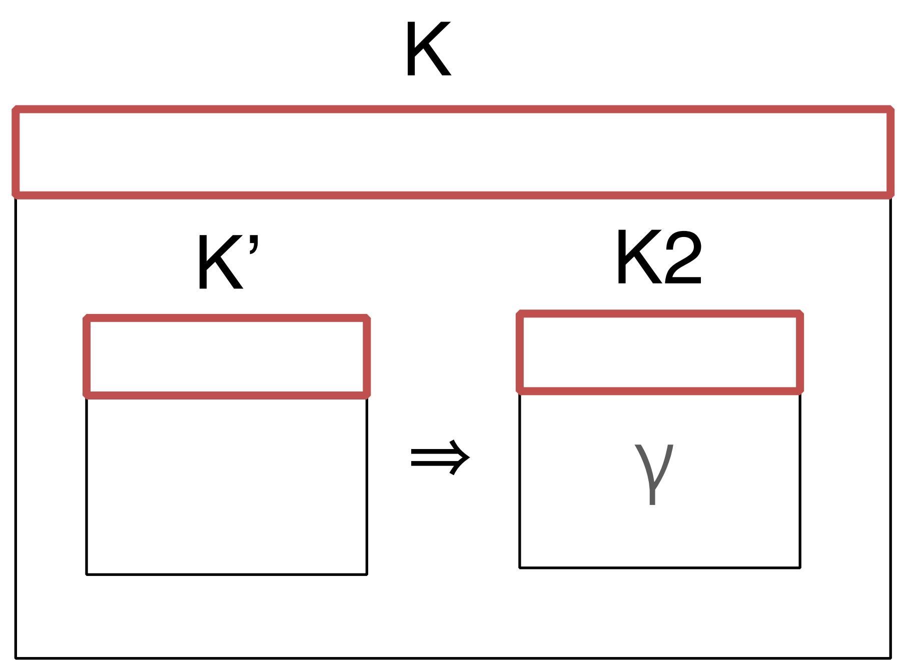


Recap: Accessibility

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_i, 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

Text	$\Sigma = \langle\ S_1,$	$S_2,$	$\ldots,$	$S_n\ \rangle$
	↓	↓		↓
Syntactic Analysis	$P(S_1)$	$P(S_2)$	$\ldots$	$P(S_n)$
	↓	↓		↓
DRS Construction	K_1 $\longrightarrow$	K_2 $\longrightarrow$	$\ldots$ $\longrightarrow$	K_n

DRS Construction Algorithm

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

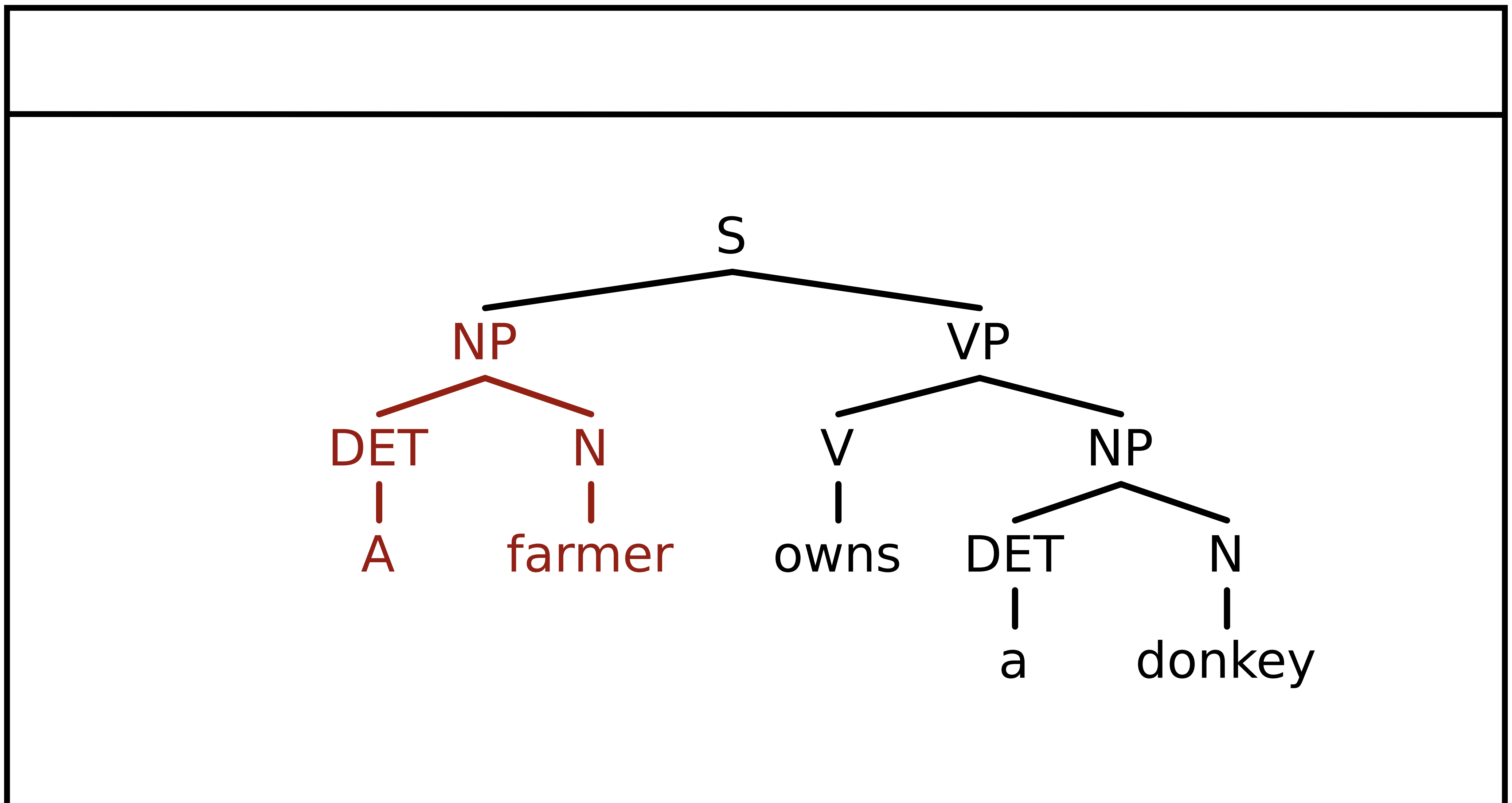
- Conditions of form α or α(x1, …, xn), where α is a context-free parse tree.

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, …, 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

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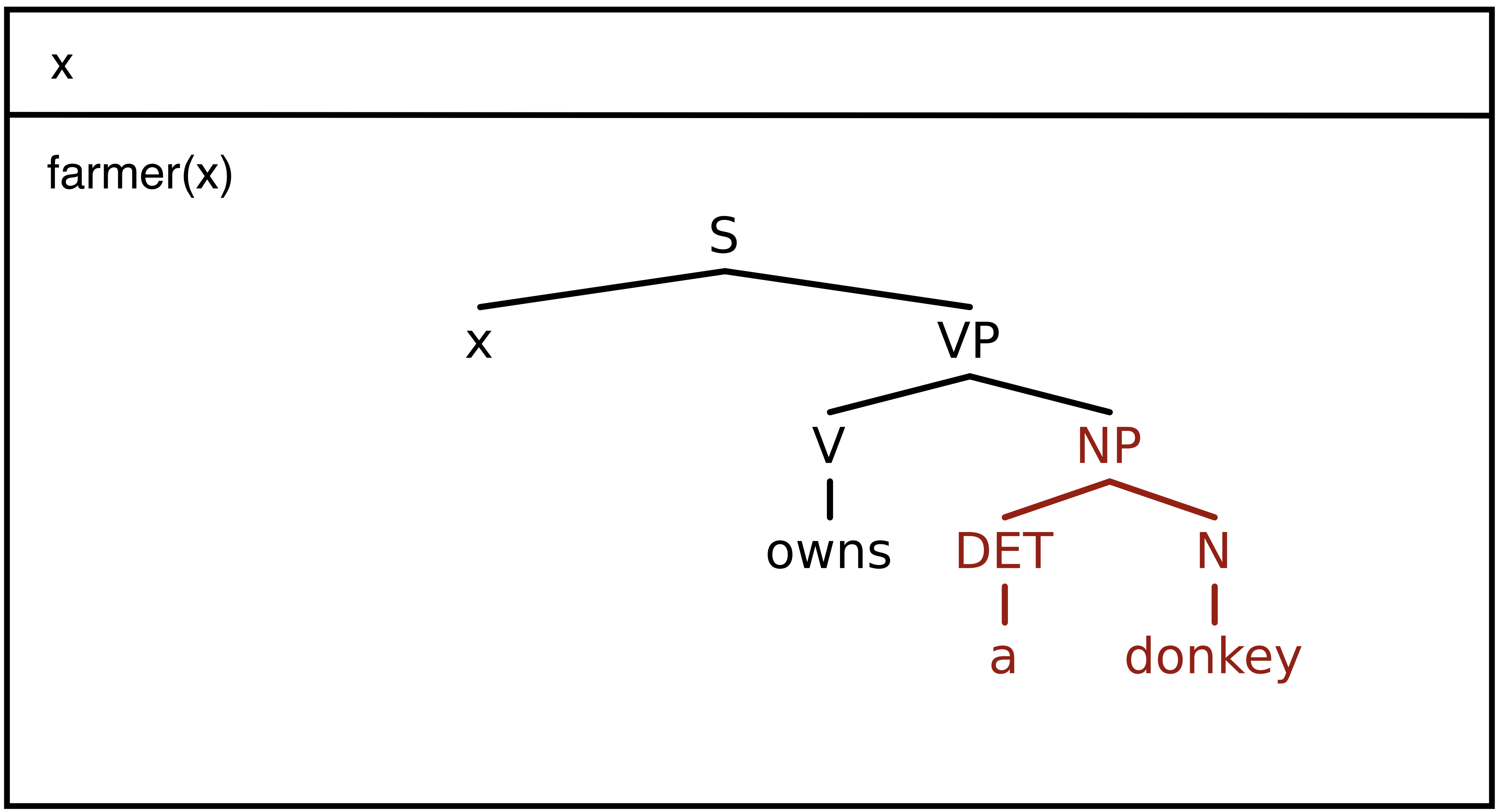


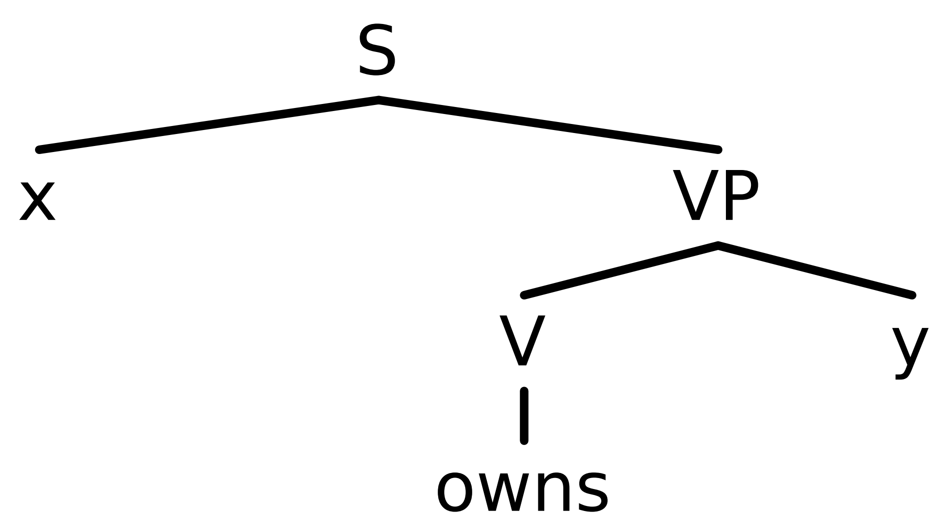
DRS Construction Example

- 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.

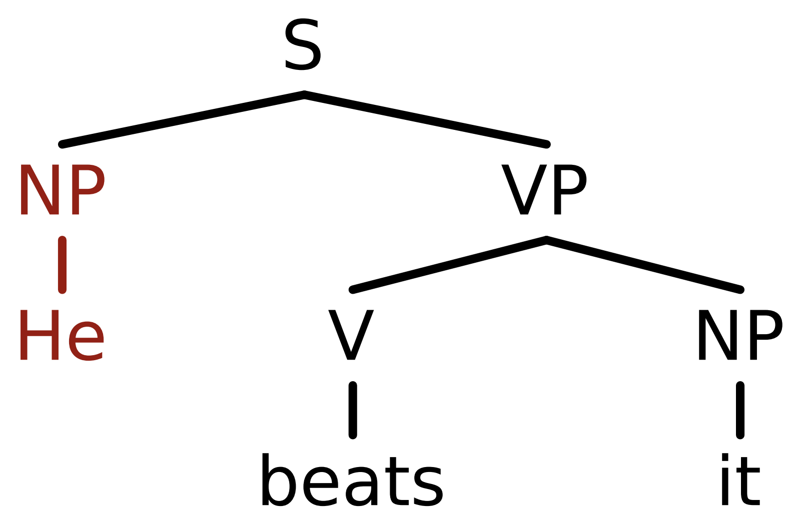
x y
farmer(x) donkey(y) owns(x, y)

DRS Construction Example

- A farmer owns a donkey. He beats it.

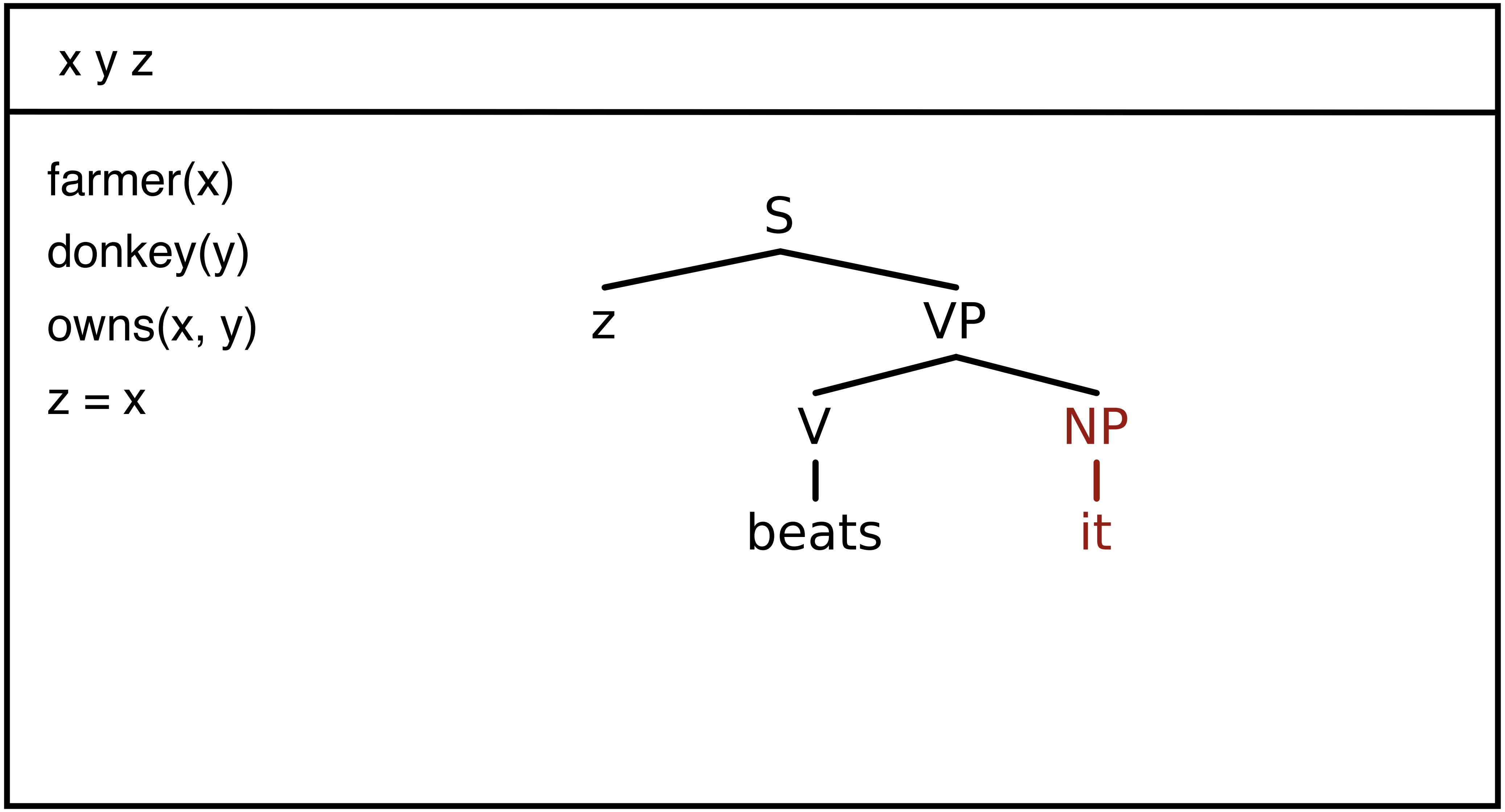
x y

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



DRS Construction Example

- A farmer owns a donkey. He beats it.



DRS Construction Example

- A farmer owns a donkey. He beats it.

x y z u

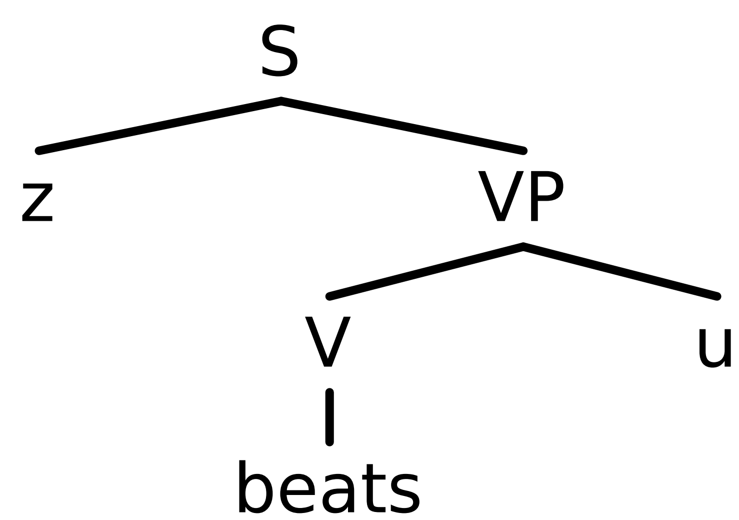
farmer(x)

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: Indefinite NPs

Triggering configuration:

- a reducible condition α in DRS K that has one of the following substructures: [S [NP β] [VP γ]] or [VP [V γ] [NP β]]
- such that: β is εδ, where ε is an indefinite article

Actions:

(i) Add a new DR x to U_K;

(ii) Replace β in α by x;

(iii) Add δ(x) to C_K.

Construction Rules: Personal Pronouns

Triggering configuration:

- a global DRS K*, and some $K \leq K^*$, with a reducible condition α in K that has one of the following substructures: [S [NP β] [VP γ]] or [VP [V γ] [NP β]]
- such that: β is a personal pronoun

Actions:

(i) Add a new DR x to U_K;

(ii) Replace β in α by x;

(iii) 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

Text	$\Sigma = \langle$	S_1,	S_2,	…,	$S_n \rangle$
		↓	↓		↓
Syntactic Analysis		$P(S_1)$	$P(S_2)$	…	$P(S_n)$
		↓	↓		↓
DRS Construction		K_1 →	K_2 →	… →	K_n
					↓

Interpretation by model embedding: Truth-conditions of Σ

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 $U_K \subseteq \mathrm{Dom}(\mathbf{f})$.

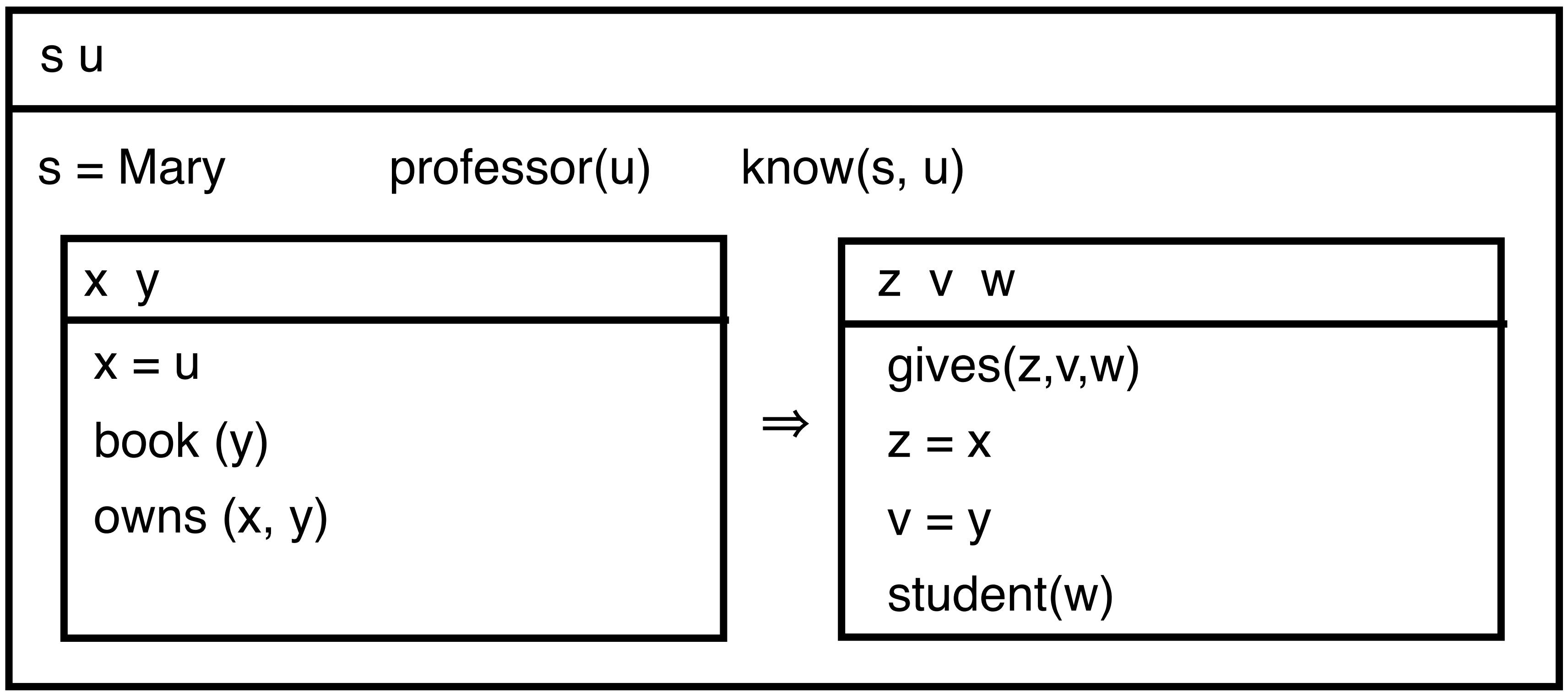
Verifying embedding

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.



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

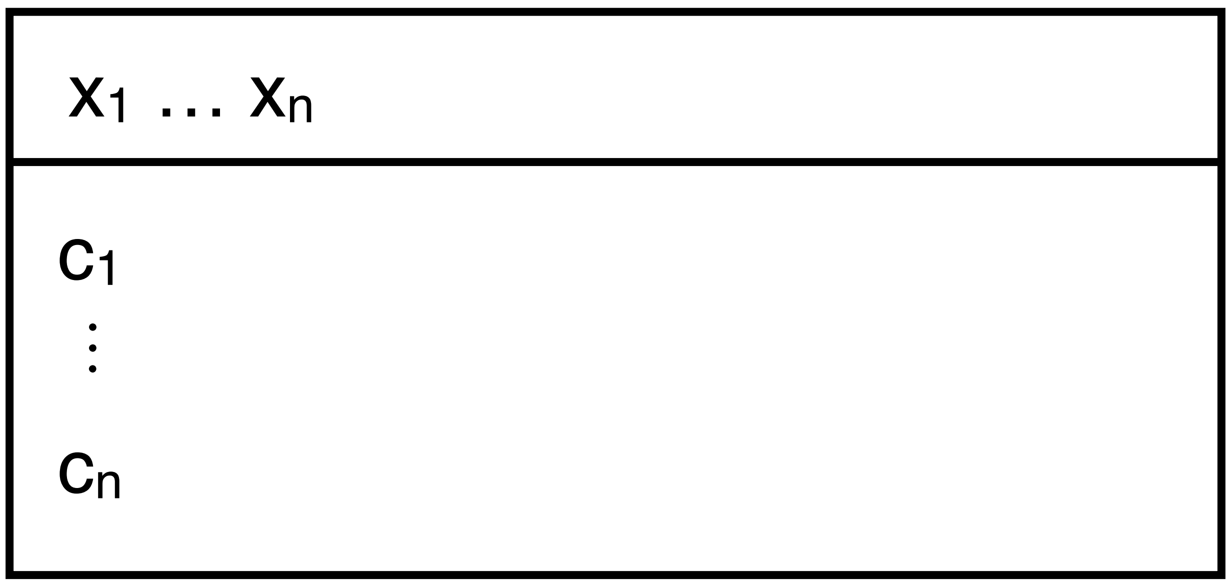
$\mathbf{f}(s) = V_M(\text{Mary})$ & $\mathbf{f}(u) \in V_M(\text{prof'})$ & $\langle \mathbf{f}(s), \mathbf{f}(u) \rangle \in V_M(\text{know})$,

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



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…

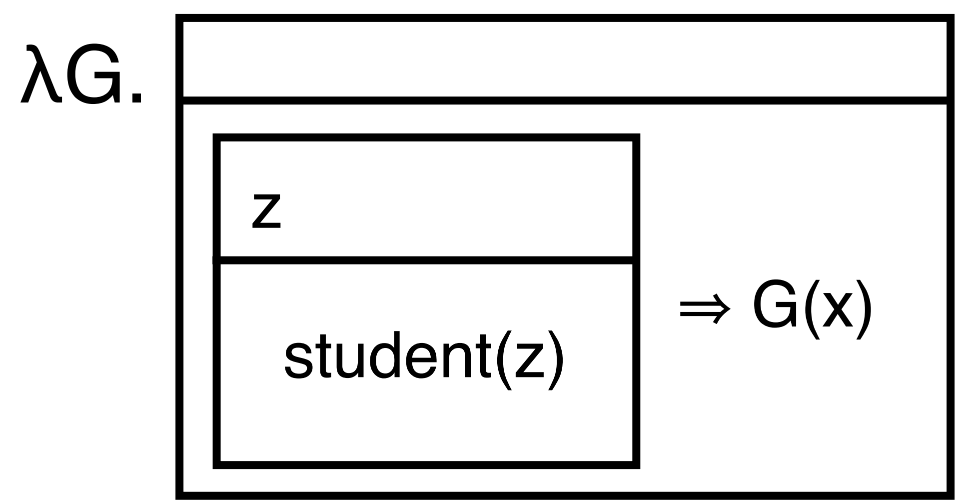
Wait a minute …

- 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⟩* ↦



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

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

λ-DRT: β-reduction

Every student works

$\mapsto$ λG[∅ | [z | student(z)] ⇒ G(z)]](λx [∅ | work(x)])

$\Rightarrow^{\beta}$ [∅ | [z | student(z)] ⇒ (λx [∅ | work(x)])(z)]

$\Rightarrow^{\beta}$ [∅ | [z | student(z)] ⇒ [∅ | work(z)]]

(Naïve) Merge

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

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

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

Merge: An example

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

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

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

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

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

Compositional analysis

- *Mary* $\mapsto$ $\lambda G\ ([\ z \mid z = \text{Mary}\ ] + G(z))$
- she $\mapsto$ $\lambda G.G(z)$

Mary works. She is successful.

$\mapsto \lambda K\ \lambda K'(K + K')([\ z \mid z = \text{Mary, work}(z)])([\ \mid \text{successful}(z)])$

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

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

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

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:

- λK’([z | student(z), work(z)] + K’)([| successful(z)])

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

  $\Rightarrow^{\beta}$ [z | 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/