Semantic Theory

Week 8: Discourse Representation Theory

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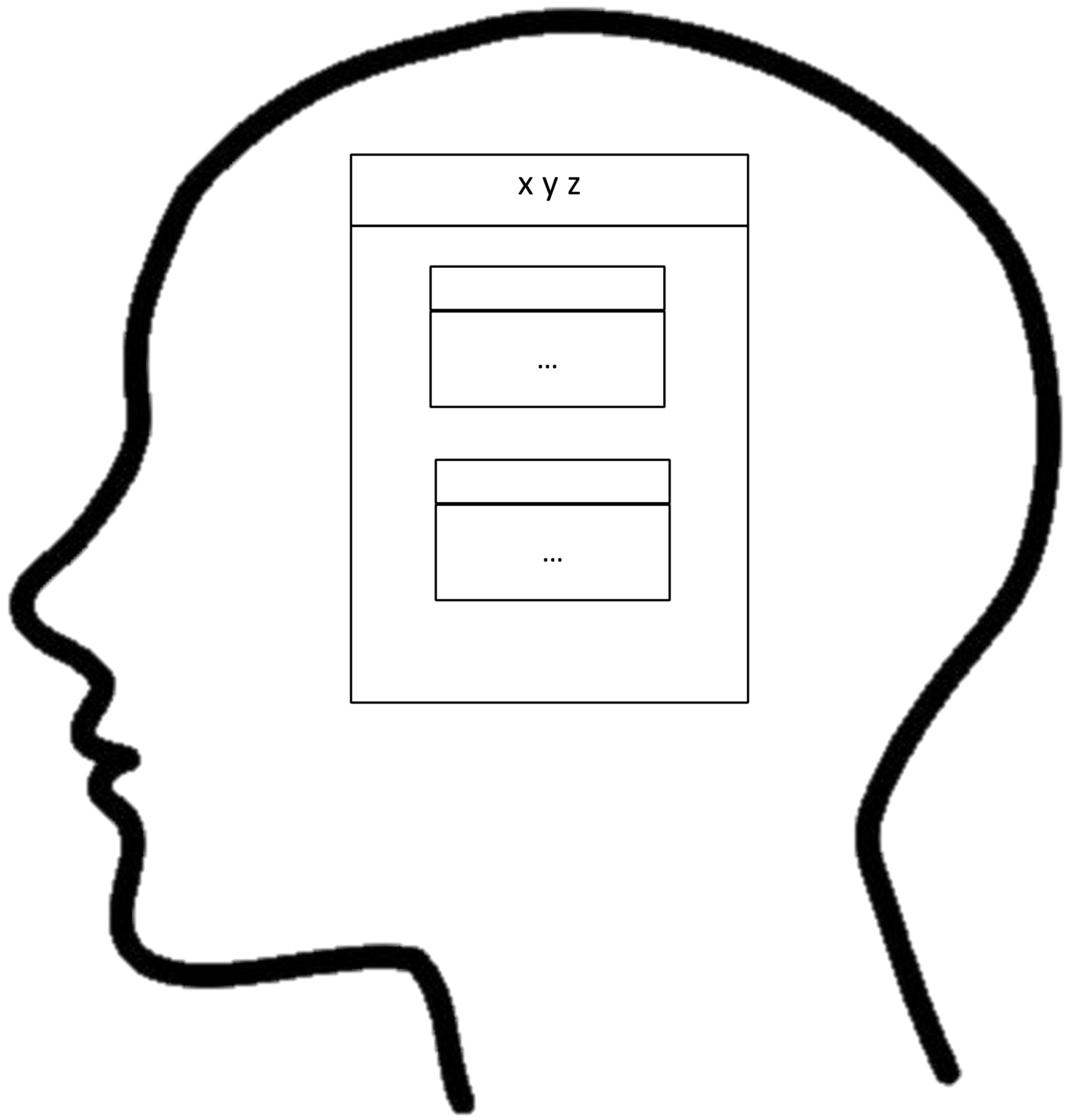
Discourse Representation Theory

Mentalist and representationalist theory of the interpretation of discourse

Ingredients:

- Discourse Representation Structures
- Construction procedure for DRSs
- Model-theoretic interpretation (at the discourse level)



(Kamp, 1981; Kamp & Reyle, 1993)

DRS Syntax

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

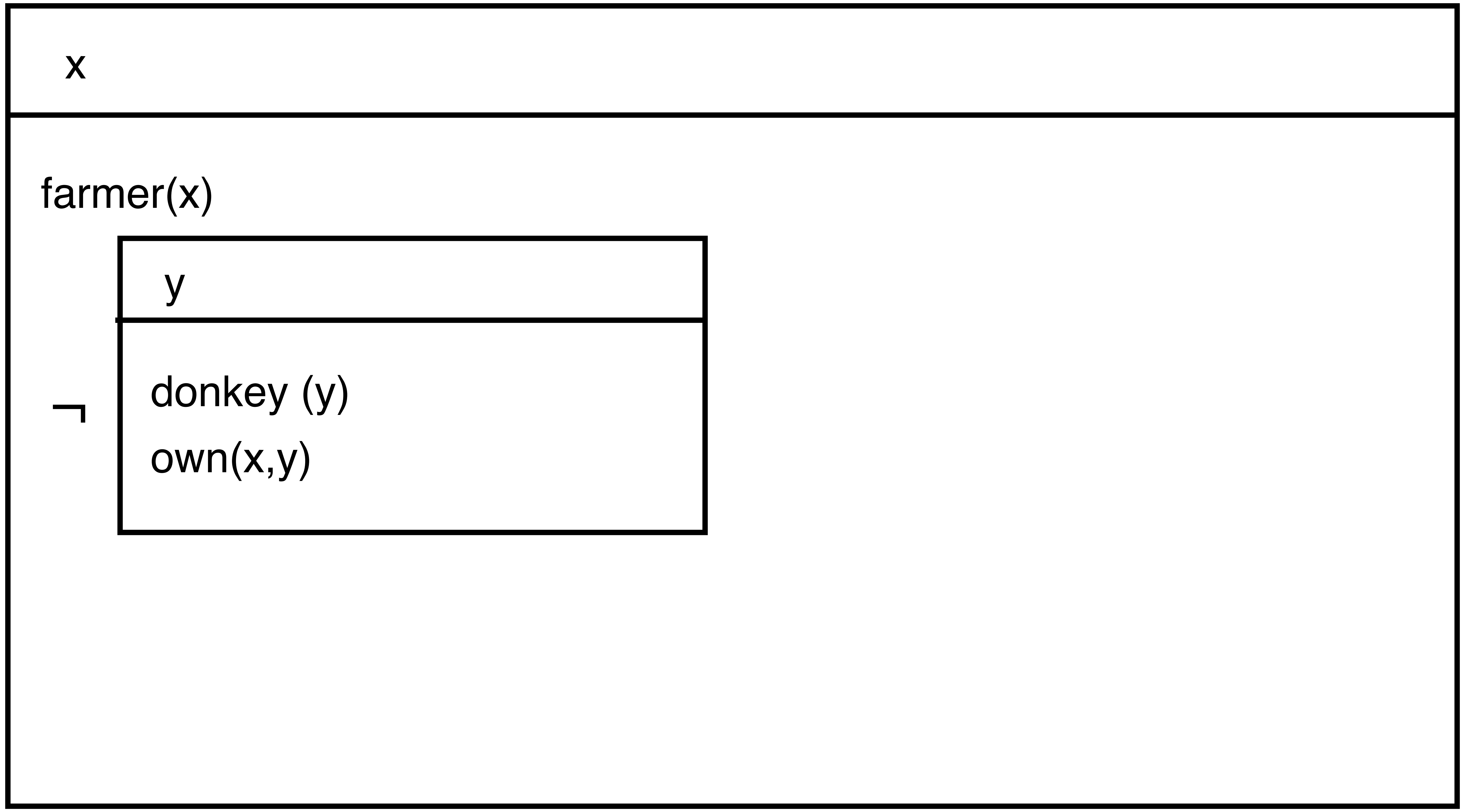
- $U_K \subseteq U_D$ and U_D is a set of discourse referents, and
- C_K is a set of well-formed DRS conditions

Well-formed DRS conditions:

• $R(u_1, \ldots, u_n)$	*where:*	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

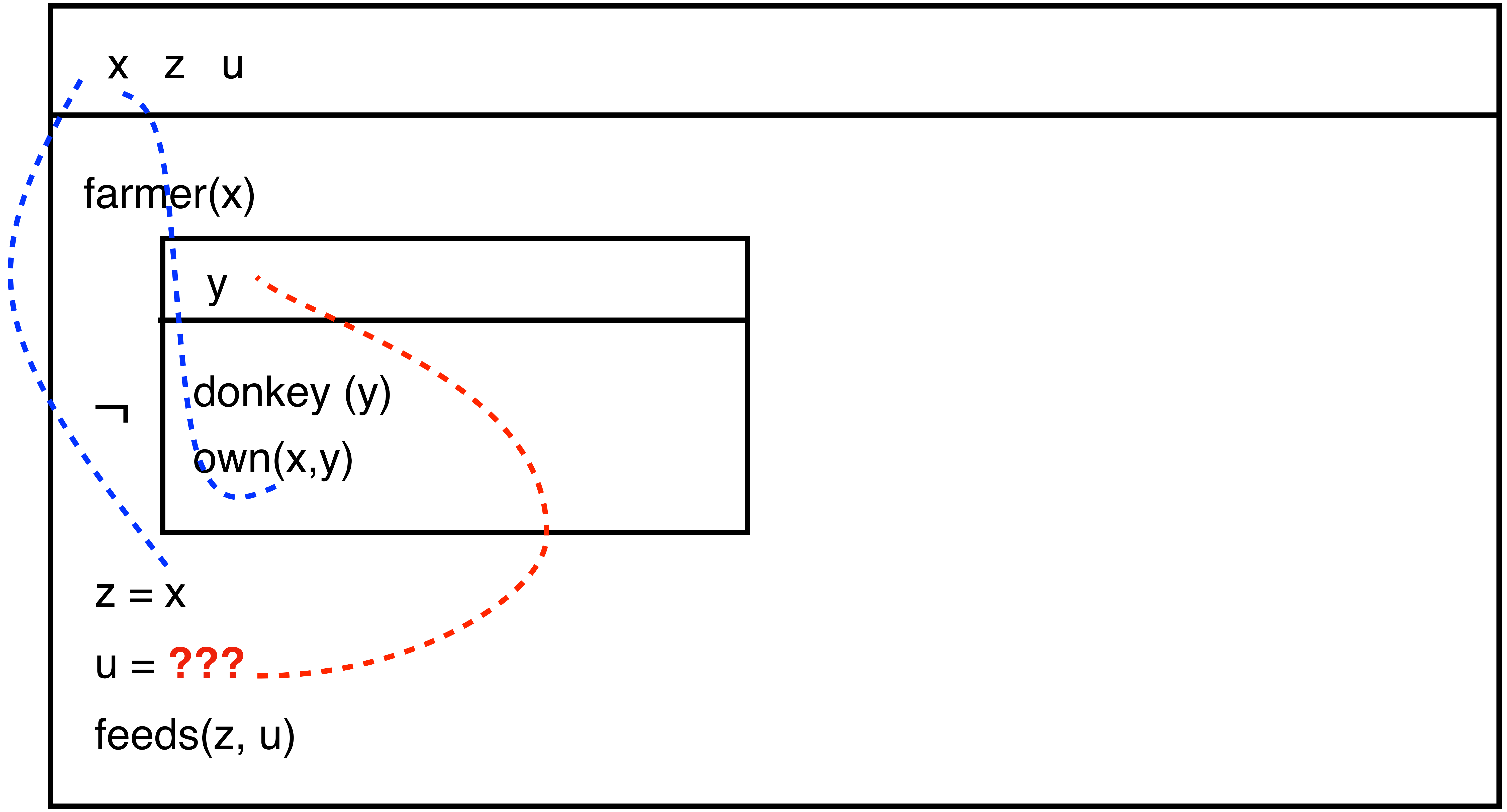
Anaphora and accessibility

A farmer does not own a donkey.



Anaphora and accessibility

A farmer does not own a donkey. # *He feeds it.*



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.*

To explain this pattern, we need to formalize accessibility of discourse referents!

Accessible discourse referents

The following discourse referents are accessible from a DRS condition:

- Referents in the same local DRS
- Referents in a superordinate DRS
- Referents in the universe of an antecedent DRS, if the condition occurs in the consequent DRS.

We need a formal notion of DRS subordination

Subordination

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 $K_2 \vee K_1$.

DRS K_1 is a **sub-DRS** of DRS 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.

DRS K_1 is a **proper sub-DRS** of DRS K *iff*

- $K_1 \leq K$ and $K_1 \neq K$.

Accessible discourse referents

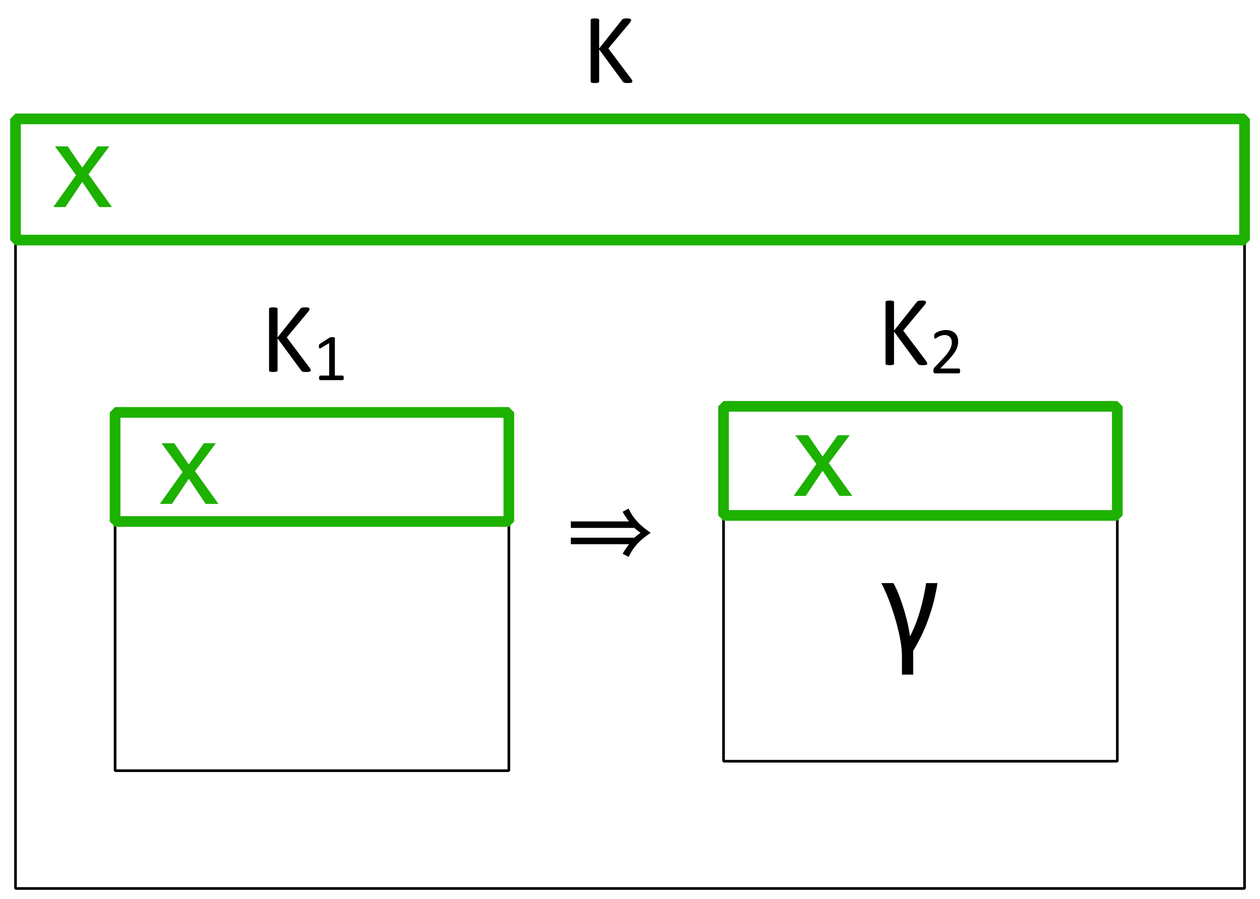
Formal definition

Let K, K_1, K_2 be DRSs such that:

$K_1, K_2 \leq K$ and $x \in U_{K_1}$ and $\gamma \in C_{K_2}$

Then, 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 the conditions of DRS K_1, is **bound** in global DRS K *iff* there exists a DRS $K_2 \leq K$, such that:

(i) $x \in U(K_2)$, and

(ii) K_2 is accessible for K_1 in K

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

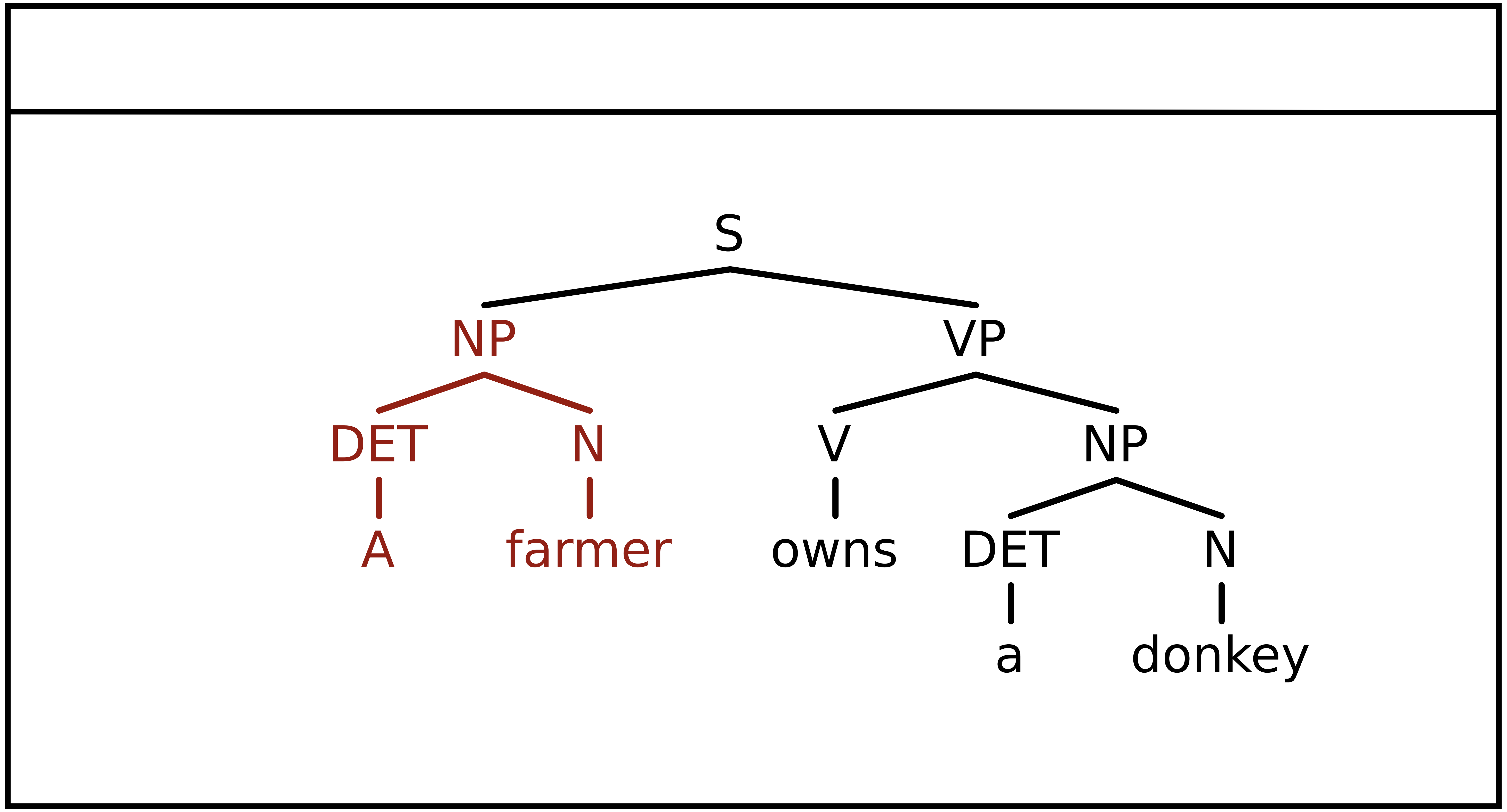
Kamp and Reyle, 1993,
From Discourse to Logic

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	

DRS Construction

Example

- A farmer owns a donkey. He beats it.



DRS Construction

Example

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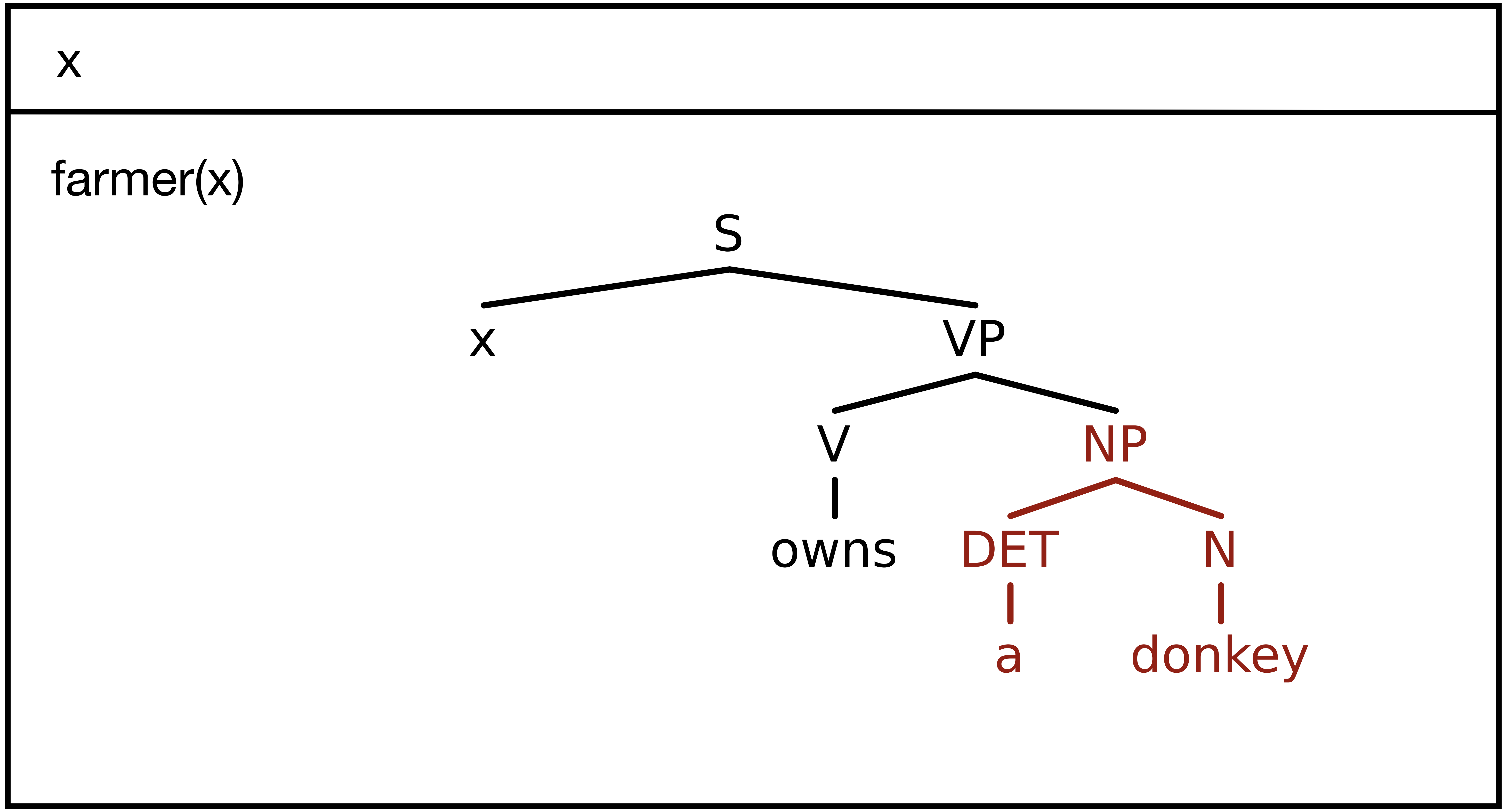

DRS Construction

Example

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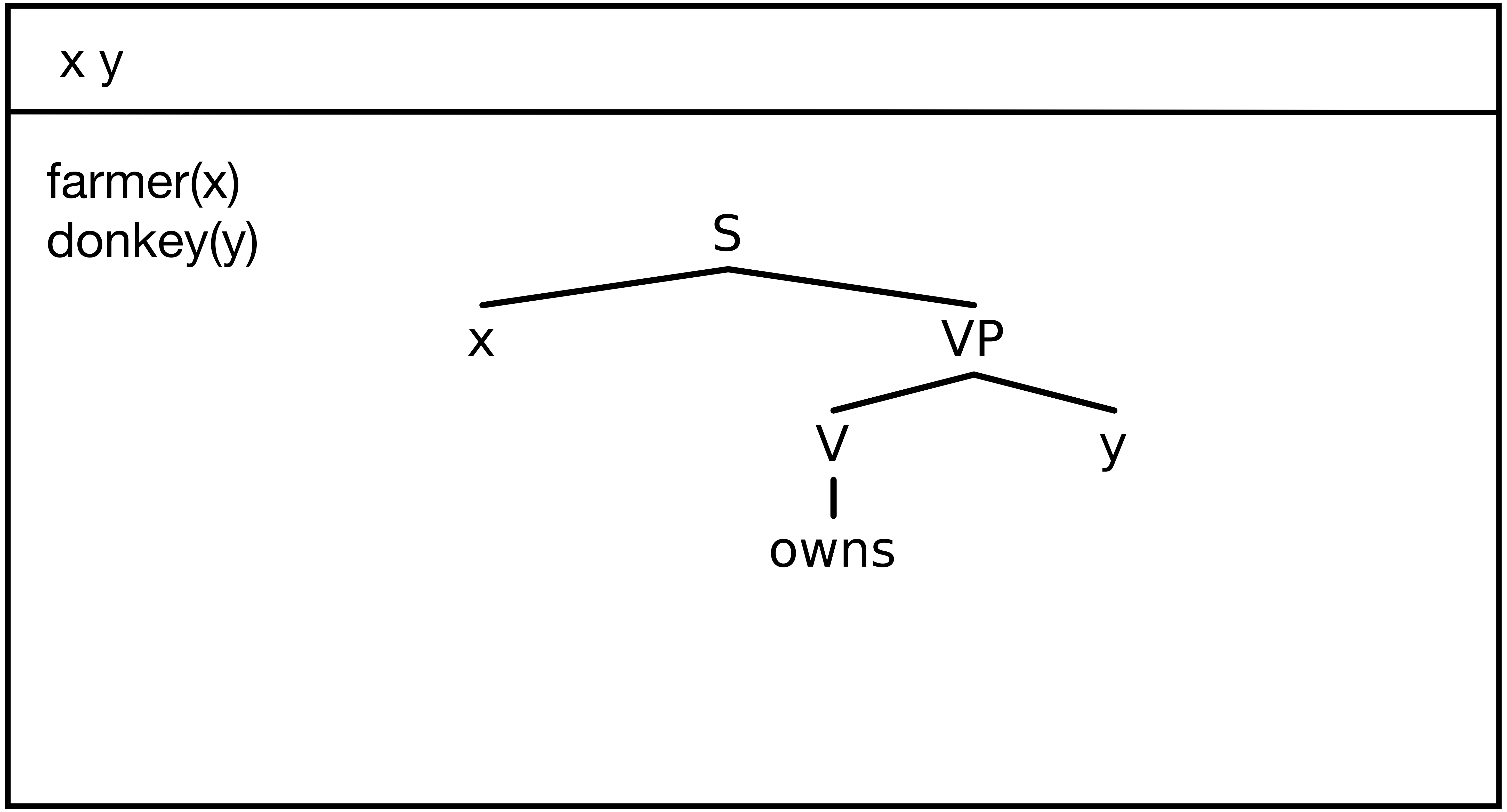


DRS Construction

Example

- A farmer owns a donkey. He beats it.

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

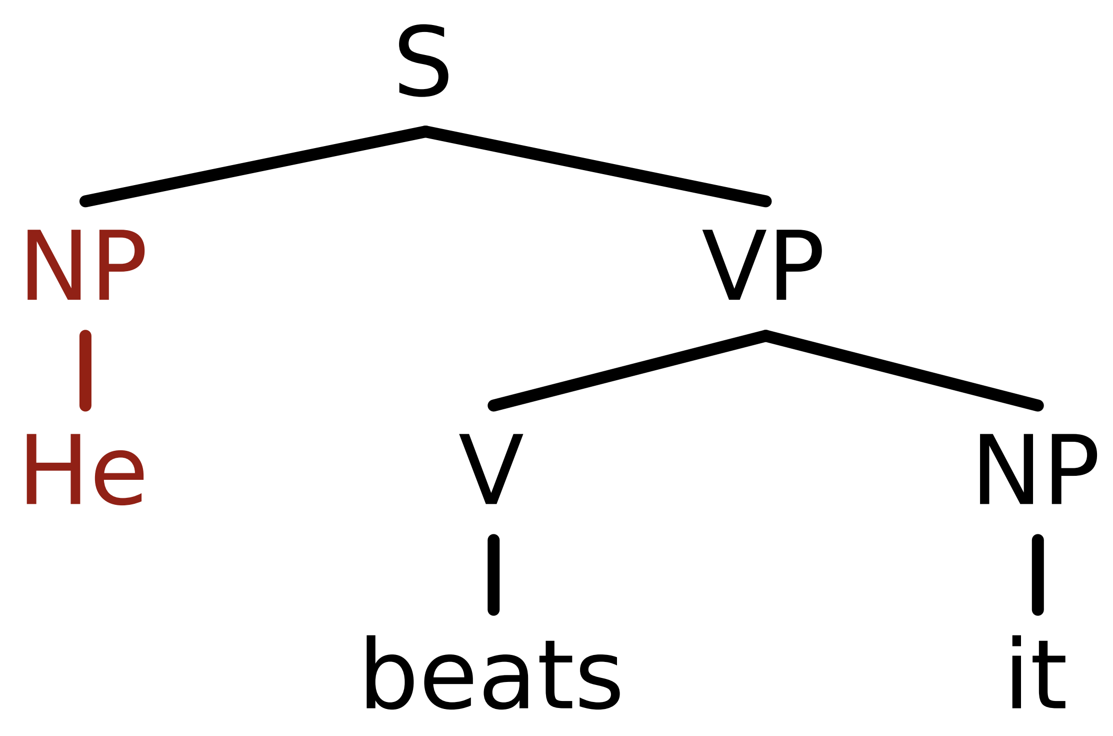
DRS Construction

Example

- A farmer owns a donkey. He beats it.

x y

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

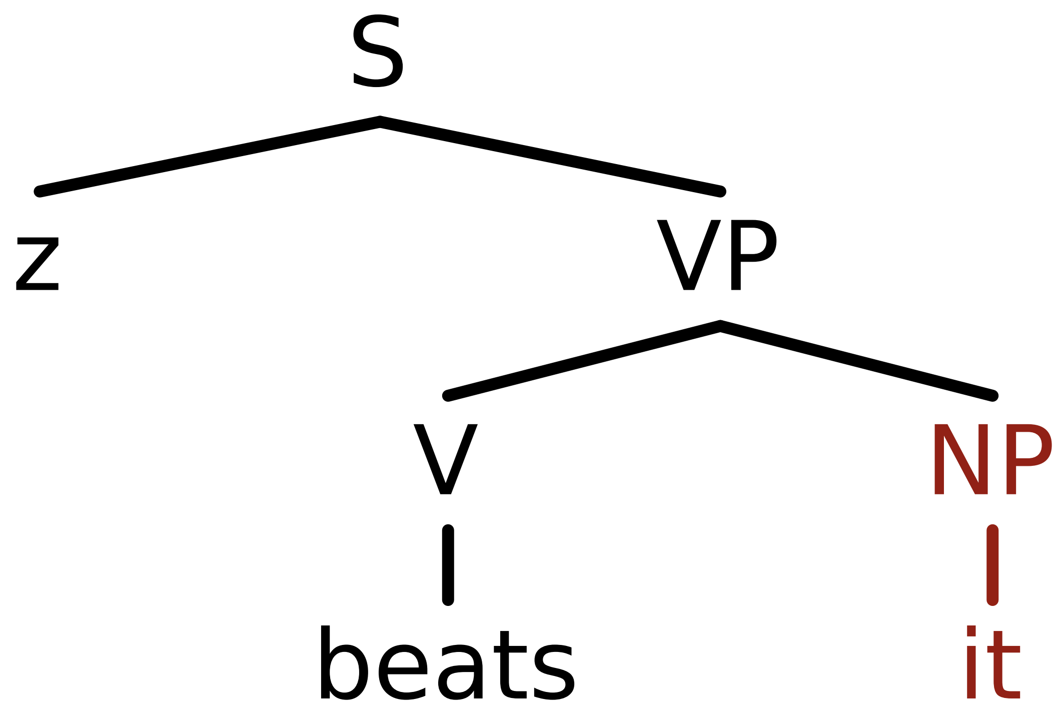


DRS Construction
Example

- A farmer owns a donkey. He beats it.

x y z

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



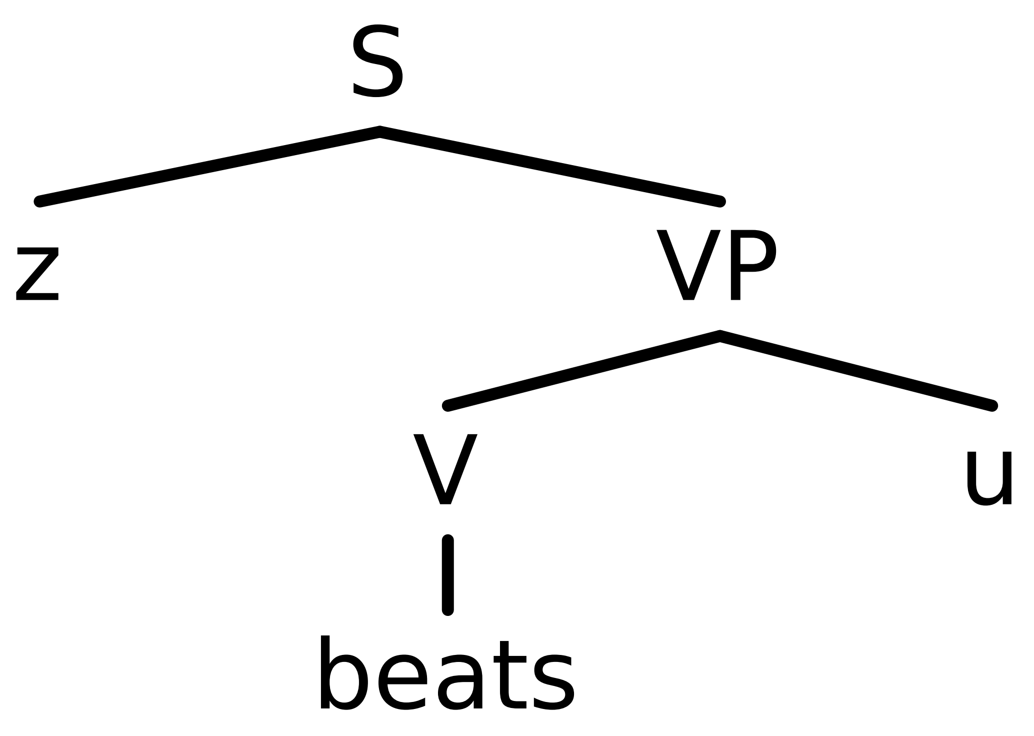
DRS Construction

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)

From text to DRS

Kamp and Reyle, 1993,
From Discourse to Logic

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

Model embedding

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 that is *appropriate for* K, i.e. a model structure that provides interpretations for all predicates and relations in K.

DRS K is true in model M *iff*

- there exists an **embedding function** for K in M that verifies all conditions in K

… *where*: an **embedding function** for DRS K in model M is defined as:
a (partial) function **f** from U_D to U_M such that $U_K \subseteq \text{Dom}(\mathbf{f})$

Verifying embedding

Using the embedding function to verify the conditions in a DRS

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** $\vDash_M \alpha$ for all $\alpha \in C_K$)

• **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** $\vDash_M K_1 \vee K_2$	*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 $\mathbf{g_2} \vDash_M K_2$
• **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** $\vDash_M K_2$

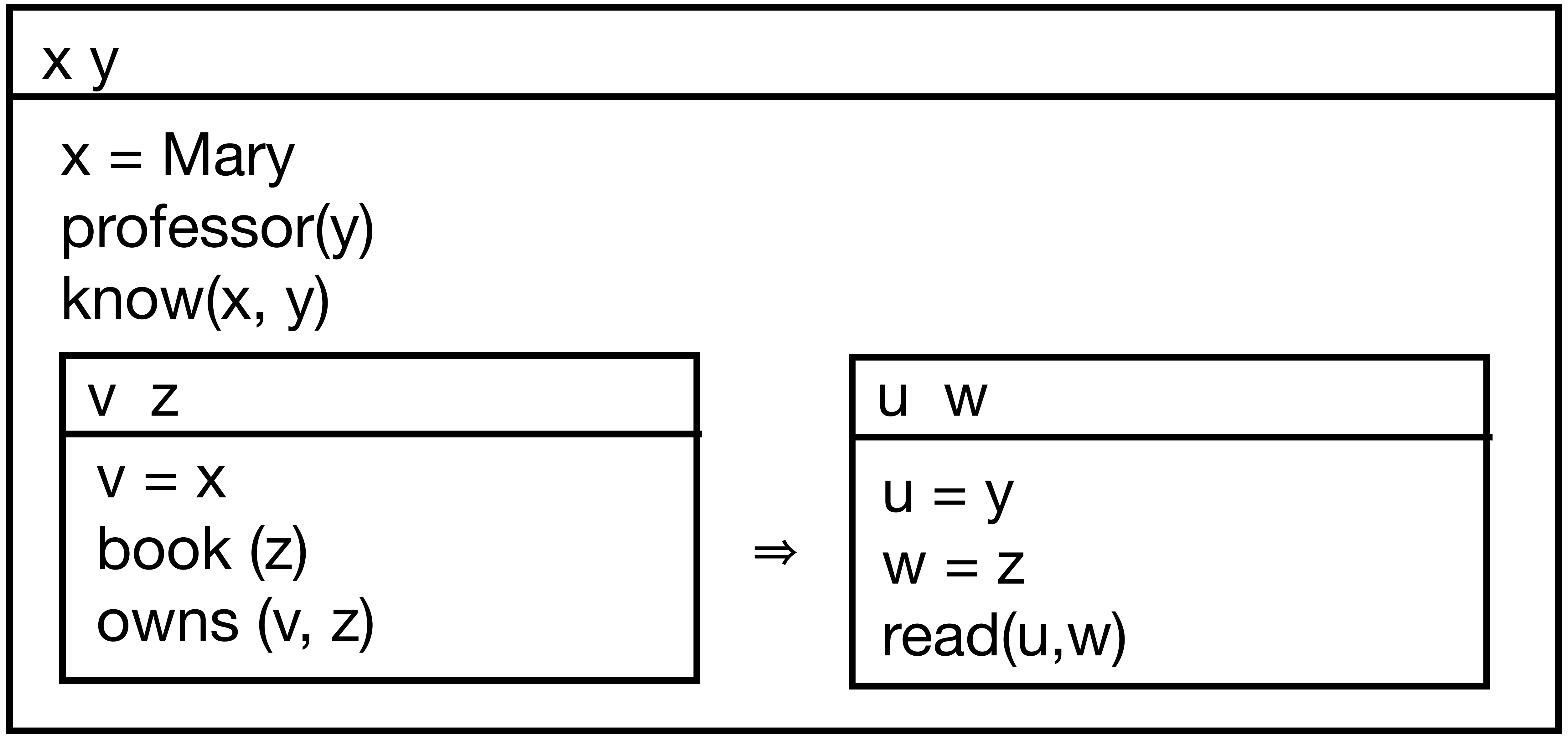
Verifying embedding

Example

Mary knows a professor.
If she owns a book,
he reads it.

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

$\mathbf{f}(x) = V_M(Mary)$ and $\mathbf{f}(y) \in V_M(prof')$ and $\langle \mathbf{f}(x), \mathbf{f}(y) \rangle \in V_M(know)$,



and for all $\mathbf{g} \supseteq_{\{v,z\}} \mathbf{f}$ such that $\mathbf{g}(v) = \mathbf{g}(x)$ $(=\mathbf{f}(x))$, $\mathbf{g}(z) \in V_M(book)$ and $\langle \mathbf{g}(v), \mathbf{g}(z) \rangle \in V_M(own)$,

there is a $\mathbf{h} \supseteq_{\{u,\, w\}} \mathbf{g}$ s.t. $\mathbf{h}(u) = \mathbf{h}(y)$ $(=\mathbf{f}(y))$ and $\mathbf{h}(w) = \mathbf{h}(z)$ $(=\mathbf{g}(z))$ and $\langle \mathbf{h}(u), \mathbf{h}(w) \rangle \in V_M(read)$.

In words: the DRS is true iff there exists an embedding function that assigns to x the model entity referred to by “Mary” and to y an entity that is in the set of “prof’s”, and these entities are in a “know” relation and for any entity that z can refer to: if that entity is in the set of “books” and “owned” by “Mary”, then it must be the case that that entity is “read” by the entity referred to by y.

Translation of DRSs to FOL

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

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

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 a representational theory of meaning
  - Structural information that cannot be reduced to truth conditions is required to compute the semantic value of discourses.
- DRT is non-compositional on truth conditions (in the traditional sense)
  - The difference in discourse-semantic status of the text pairs is not predictable through the truth conditions of its component sentences.

But wait a minute… can't we just combine type theoretic semantics and DRT?

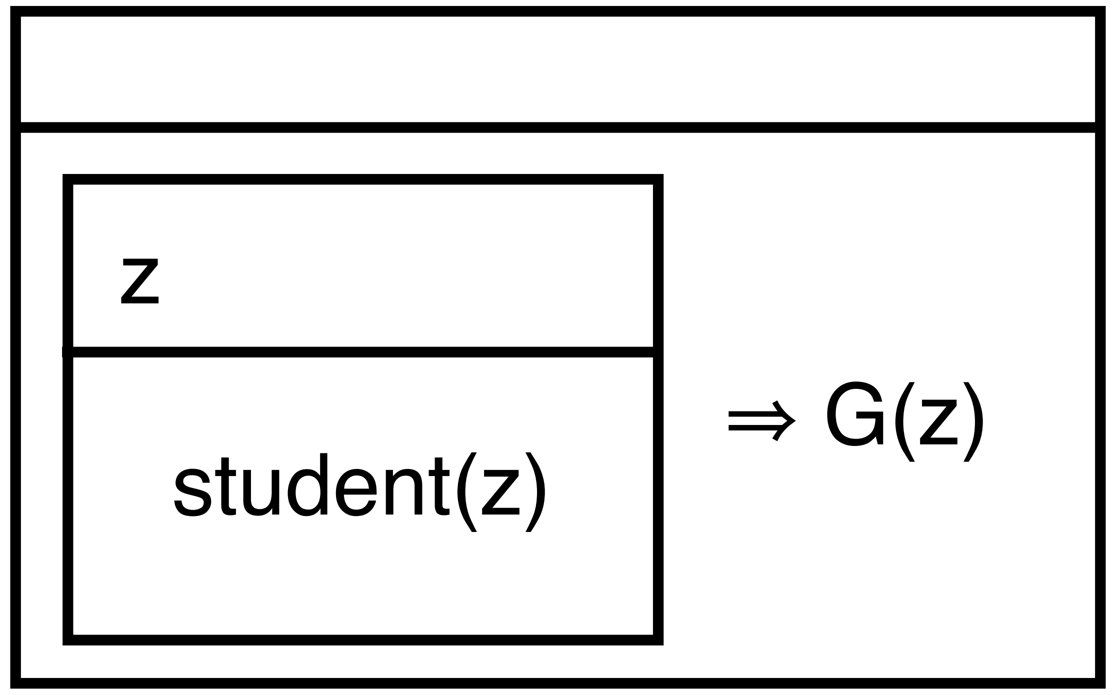
- Use λ-abstraction and reduction as we did before, but assume that the target (type t) representations that we want to arrive at are not formulas from type theory (or FOL), but DRSs.

The result is called λ-DRT.

λ-DRT

Reinhard Muskens (1996), *Ling. and phil.*

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

- *every student* :: $\langle\langle e, t\rangle, t\rangle$ ↦ λG. 

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

- *works* :: $\langle e, t\rangle$ ↦ 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)]]

Question: How do we define conjunction on DRSs?

Simple DRS Merge

First try

The “merge” operation on two DRSs combines the universes and conditions of both DRSs into a new DRS.

- Let K_1 = [U1 | C1] and K_2 = [U2 | C2].

Merge: $K_1 + K_2$ = [U1 ∪ U2 | C1 ∪ C2]

Compositional analysis with Merge

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 with Merge

Example with pronouns

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

Mary works. She is successful.

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

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

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

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

DRS Merge again

Directional variable capturing

The “merge” operation on two DRSs combines the universes and conditions of both DRSs into a new DRS.

- Let K_1 = [U1 | C1] and K_2 = [U2 | C2].

Merge: $K_1 + K_2 = [\ U1 \cup U2 \mid C1' \cup C2\ ]$

where: C1’ is C1 such that all free variables in the conditions $\gamma \in$ C1 that also occur as discourse referents $u \in$ U2 are α-converted to new variables

Note that under this definition Merge is directional:
$K_1 + K_2 \not\Leftrightarrow K_2 + K_1$

Variable capturing

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

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

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

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

- But the β-reduced DRS must be *equivalent* to the original DRS!
- This means that the potential for capturing discourse referents must be captured in the interpretation of λ-DRSs.

➜ Possible, but tricky.

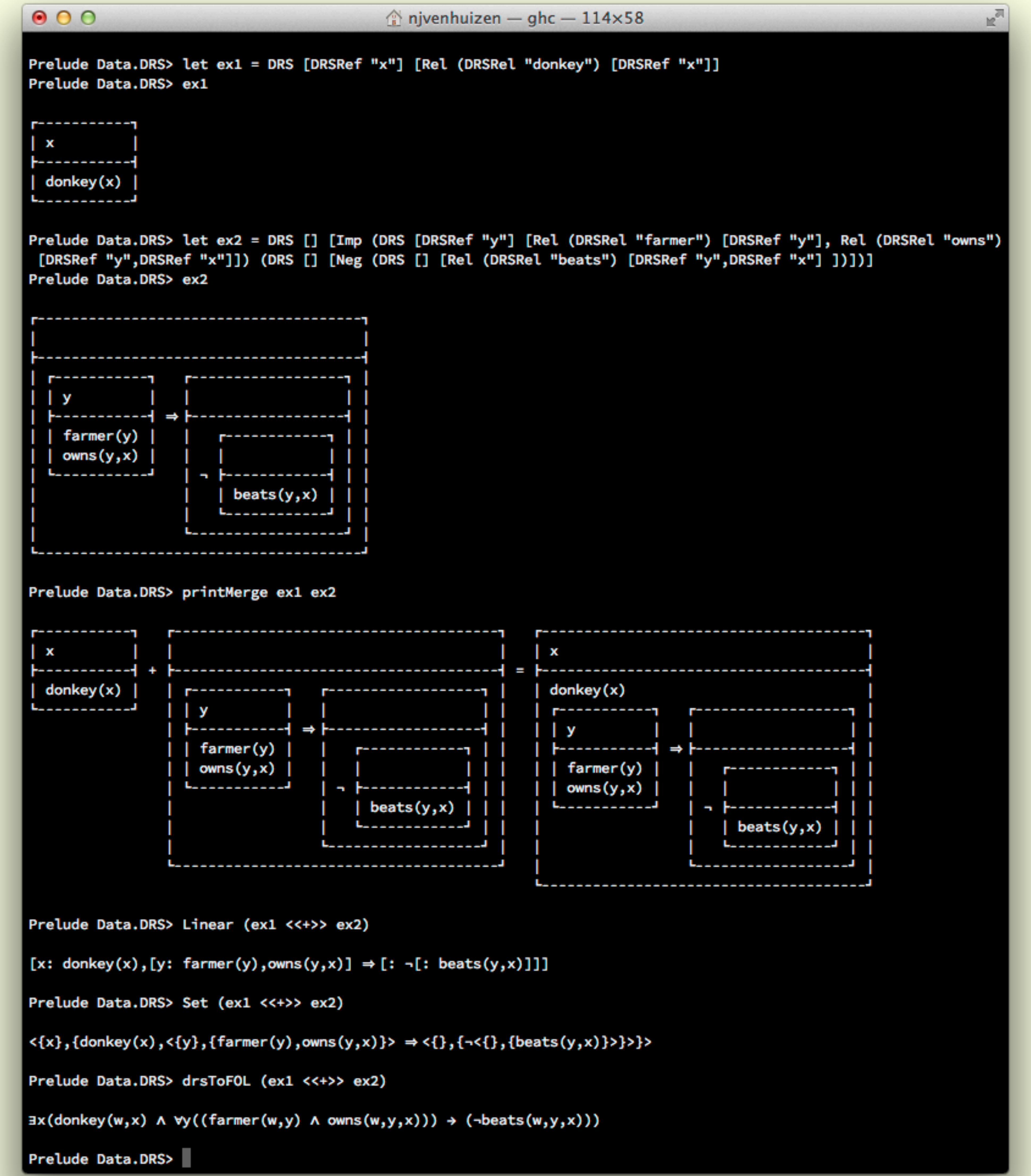
Introducing: PDRT-SANDBOX

PDRT-SANDBOX is a Haskell library that implements Discourse Representation Theory (and the extension Projective DRT)

http://hbrouwer.github.io/pdrt-sandbox/
also available via: login.coli.uni-saarland.de:/proj/courses/semantics-19

- Define your own DRSs, using the internal syntax or the set-theoretic notation
- Show the DRSs in different output formats (boxes, linear, set-theoretic, internal syntax)
- Composition of DRSs (using lambda's)
- Translate DRSs to FOL formulas

Playing in the Sandbox



DRS Syntax in PDRT-SANDBOX

PDRT SANDBOX

DRS: `DRS […] […]` referents conditions

Referents: `DRSRef “x”, DRSRef “Mary”`

Conditions:

- Relation: `Rel (DRSRel "man") [DRSRef “x"]`
- Identity: `Rel (DRSRel "=") [DRSRef “x”,DRSRef “y"]`
- Negation: `Neg (DRS […] […])`
- Implication: `Imp (DRS […] […]) (DRS […] […])`
- Disjunction: `Or (DRS […] […]) (DRS […] […])`

Properties: `isPure(DRS […] […]), isProper(DRS […] […])`

Using PDRT-SANDBOX on coli

```
~$ cp -r /proj/courses/semantics-19/pdrt-sandbox/ .
~$ cp /proj/courses/semantics-19/ghci .ghci
~$ cd pdrt-sandbox/
~/pdrt-sandbox$ make
[…]
~/pdrt-sandbox$ cd tutorials/
~/pdrt-sandbox/tutorials$ ghci DRSTutorial.hs
GHCi, version 7.10.3: http://www.haskell.org/ghc/  :? for help
[1 of 1] Compiling Main             ( DRSTutorial.hs, interpreted )
Ok, modules loaded: Main.
*Main>
```

Literature

References:

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

- Reinhard Muskens. "Combining Montague semantics and discourse representation." *Linguistics and philosophy* (1996): 143-186.

Background reading:

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