Semantic Theory
Lecture 14: Discourse Semantics II

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Discourse Representation Theory

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

An 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)

Denotational Interpretation

- Let
  - $K = \langle U_K, C_K \rangle$ a DRS
  - $M = \langle U_M, V_M \rangle$ a FOL model structure appropriate for K (i.e., M provides interpretations for all relation symbols occurring in K).
- An embedding of K into M is a function f from U_K to U_M.

Verifying embedding

- **An embedding** f of K in M **verifies K in M** iff f verifies every condition $\alpha \in C_K$
  - Notation: $f \vDash_M K$
- **f verifies condition α in M** ($f \vDash_M \alpha$):
  - $f \vDash_M R(x_1, \ldots, x_n)$ iff $\langle f(x_1), \ldots, f(x_n) \rangle \in V_M(R)$
  - $f \vDash_M x = a$ iff $f(x) = V_M(a)$
  - $f \vDash_M x = y$ 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.

Verifying Embedding: Example

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 $|=_M$ K iff f verifies every condition $\alpha \in C_K$, i.e.:

  f $|=_M$ professor(x), f $|=_M$ book(y) f $|=_M$, own(x,y) ,

  f $|=_M$ read(z,u) , f $|=_M$ z=x , and f $|=_M$ u=y

- This holds iff:

  f(x)$\in V_M$(professor) , f(y)$\in V_M$(book), $\langle$f(x), f(y)$\rangle \in V_M$(own),

  $\langle$f(z), f(u)$\rangle \in V_M$(read), f(z)=f(x) , and f(u)=f(y)

Simplification

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

iff

- $f(x) \in V_M(\text{professor}) \wedge f(y) \in V_M(\text{book}) \wedge \langle f(x), f(y) \rangle \in V_M(\text{own}) \wedge \langle \mathbf{f(x)}, f(u) \rangle \in V_M(\text{read}) \wedge f(u) = f(y)$

- $f(x) \in V_M(\text{professor}) \wedge f(y) \in V_M(\text{book}) \wedge \langle f(x), f(y) \rangle \in V_M(\text{own}) \wedge \langle f(x), f(u) \rangle \in V_M(\text{read}) \wedge \mathbf{f(u) = f(y)}$

iff

- $f(x) \in V_M(\text{professor}) \wedge f(y) \in V_M(\text{book}) \wedge \langle f(x), f(y) \rangle \in V_M(\text{own}) \wedge \langle f(x), \mathbf{f(y)} \rangle \in V_M(\text{read})$

Truth: Example

- $K = < \{x, y, z, u\},$

  $\{professor(x), book(y), own(x,y), read(z,u), z=x, u=y\} >$

- Embedding f verifies K in M: $f \models_M K$

  iff f verifies every condition $\alpha \in C_K$

  iff $f(x) \in V_M(professor) \wedge f(y) \in V_M(book) \wedge \langle f(x), f(y) \rangle \in V_M(own) \wedge$

  $\langle f(x), f(y) \rangle \in V_M(read)$

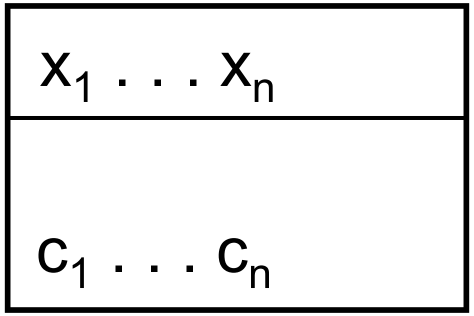
- **K is true in M iff there is an f such that $f \models_M K$**

The Basic Contribution of DRT

- DRT provides an integrated model of global anaphoric relations (through DRS construction) and truth-conditional semantics (through model embedding).

- In particular, DRT models the ambivalent status of indefinite NPs: Indefinite noun phrases introduce new reference objects into context, and at the same time express existential quantification.

Translation of DRSes to FOL



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

  is truth-conditionally equivalent to the FOL formula:

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

Indefinite NPs and Conditionals

(1) *If a student works, the professor is happy.*

(2) $\exists x[\text{student}(x) \wedge \text{work}(x)] \rightarrow \text{happy}(\text{the-professor})$

(3) $\forall x[\text{student}(x) \wedge \text{work}(x) \rightarrow \text{happy}(\text{the-professor})]$

- Formulas (2) and (3) are logically equivalent:
- $\exists xA \rightarrow B \;\Leftrightarrow\; \forall x[A \rightarrow B]$ (provided that variable x does not occur free in B)

Statives and Non-Statives: Linguistic Evidence

- *If a student works, she will be successful.*

(1) $\exists x[student(x) \land work(x)] \rightarrow successful(x)$

(2) $\exists x[student(x) \land work(x) \rightarrow successful(x)]$

(3) $\forall x[student(x) \land work(x) \rightarrow successful(x)]$

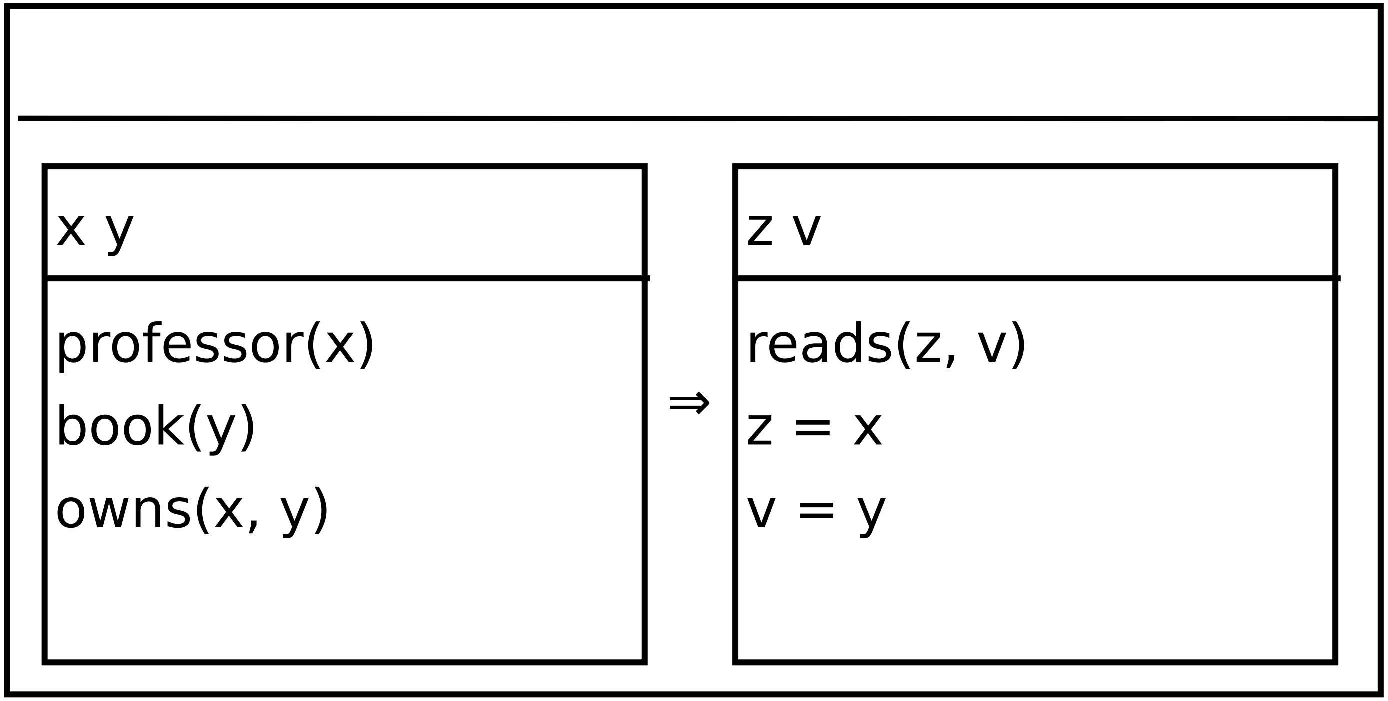
- Formula (1) is not closed (x occurs free)
- Formula (2) has wrong truth conditions (much too weak)
- Formula (3) is correct, but how can it be derived compositionally?

Indefinite NPs in Hypothetical Text

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

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



DRS (1^{st} Extension)

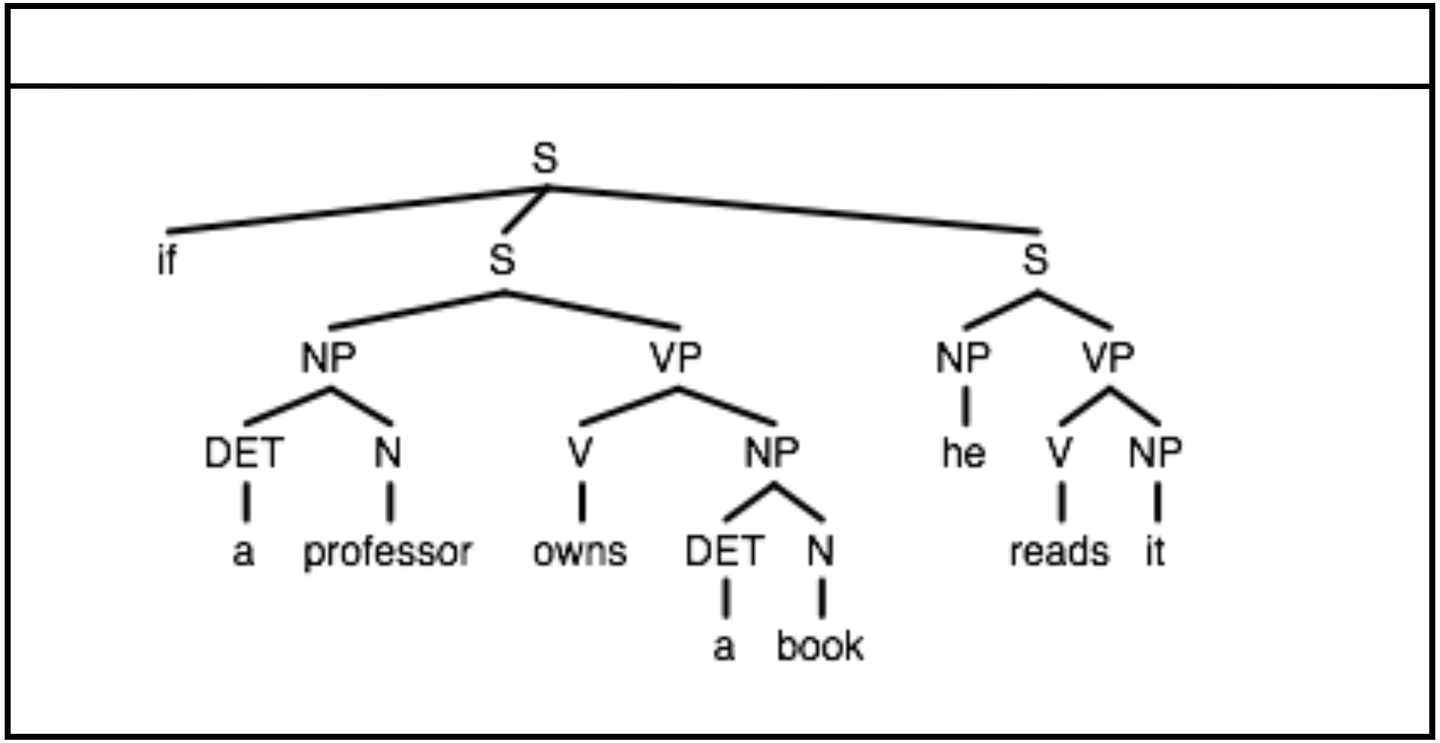
- **A discourse representation structure (DRS)** K is a pair $\langle U_K, C_K \rangle$, where
  - U_K is a set of discourse referents
  - C_K is a set of conditions
- **(Irreducible) conditions:**
  - $R(u_1, \ldots, u_n)$ R n-place relation, $u_i \in U_K$
  - $u = v$ $u, v \in U_K$
  - $u = a$ $u \in U_K$, a is a proper name
  - $\mathbf{K_1 \Rightarrow K_2}$ **K_1 and K_2 DRSs**
- **Reducible conditions:** as before

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
    - $K_1 = \langle \emptyset, \{ \beta \} \rangle$
    - $K_2 = \langle \emptyset, \{ \gamma \} \rangle$
- Remark: $K_1 \Rightarrow K_2$ is called a **duplex condition**; K_1 the "antecedent DRS" and K_2 the "consequent DRS."

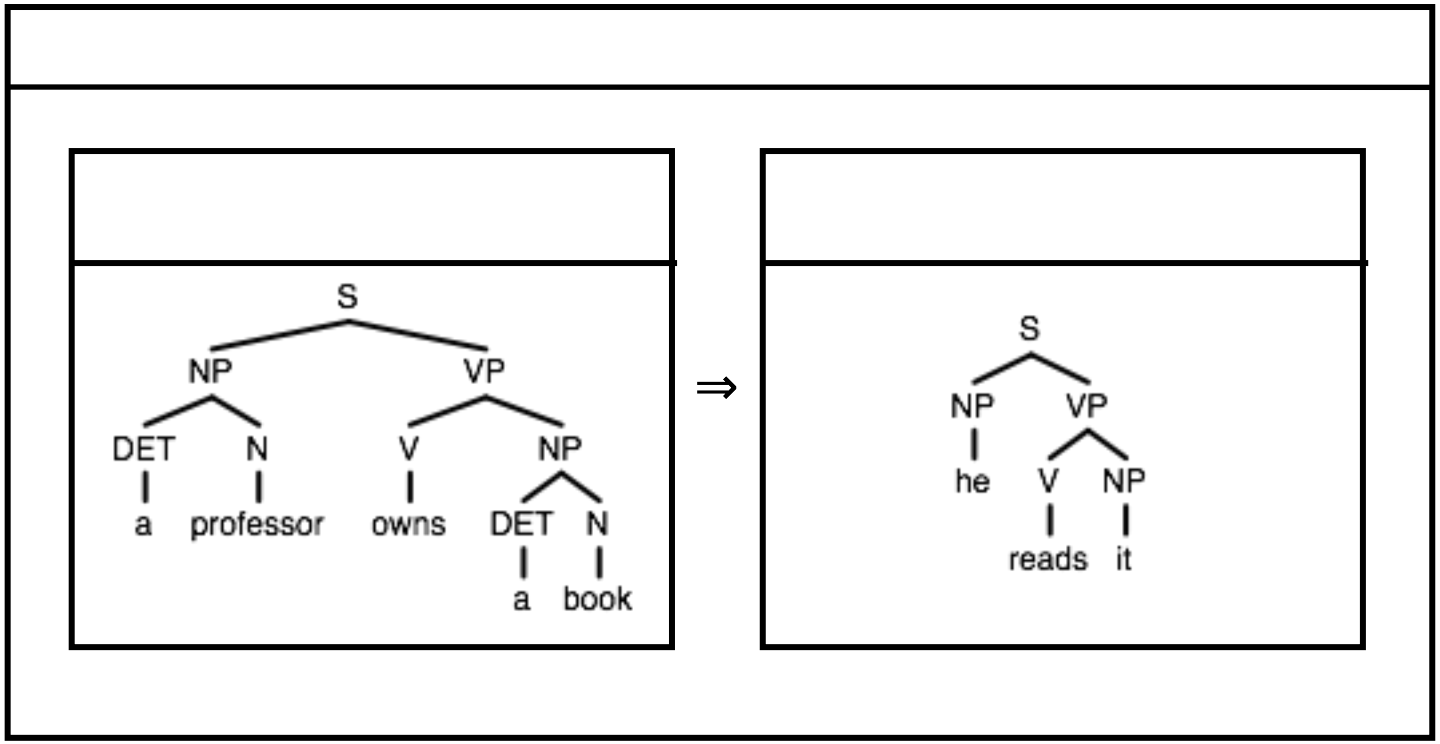
An Example

If a professor owns a book, he reads it.



An Example

If a professor owns a book, he reads it.



An Example

If a professor owns a book, he reads it.

x y

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

⇒

z v

reads(z, v)
z = x
v = y

Embedding: Basic Version

- Let $K = \langle U_K, C_K \rangle$ a DRS, $M = \langle U_M, V_M \rangle$ an FOL model structure appropriate for K. An embedding of K into M is a function f from U_K to U_M.

- 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 $f(x) = V_M(a)$

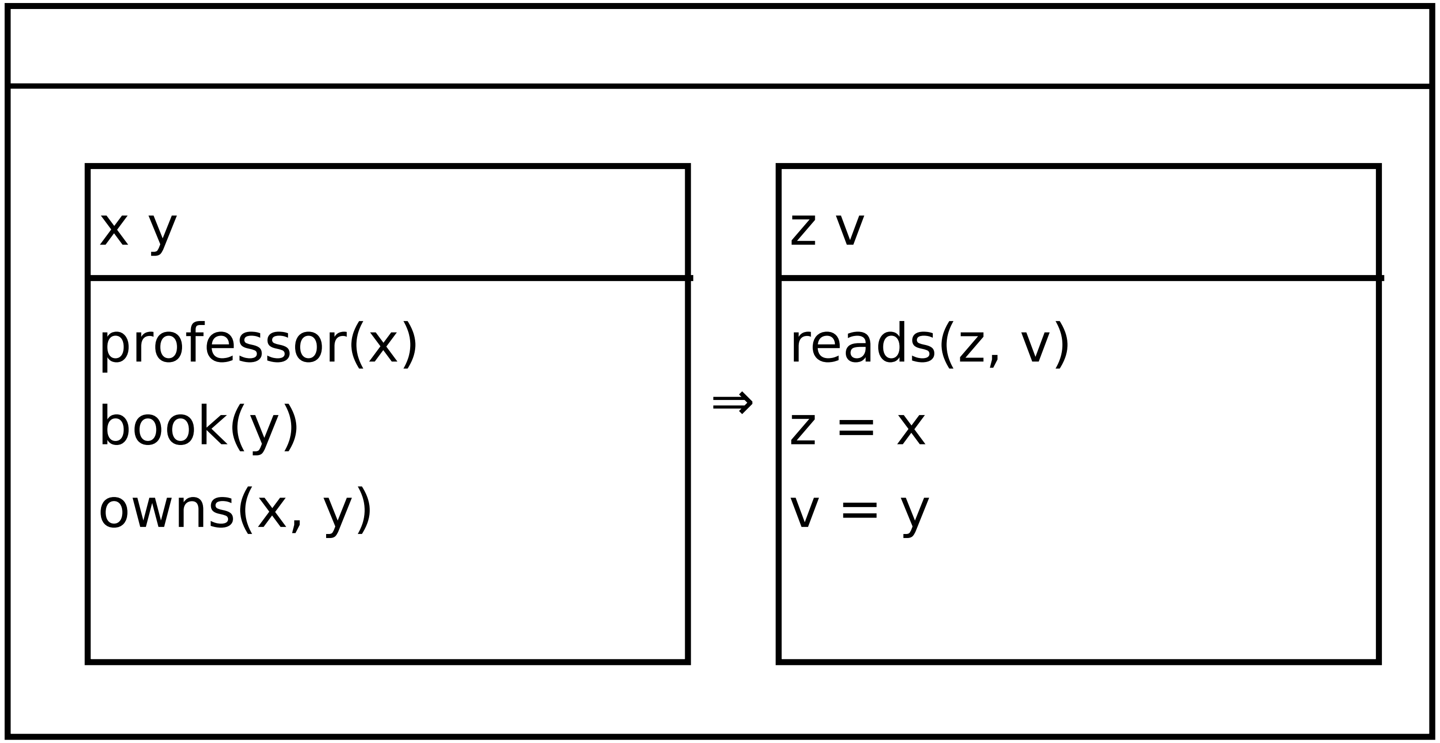
  (iii) $f \models_M x = y$ iff $f(x) = f(y)$

Verifying Embedding for Duplex Conditions (Preliminary)

- **$f \models_M K_1 \Rightarrow K_2$**
  iff for all $g \supseteq_{UK_1} f$ such that $g \models_M K_1$, also $g \models_M K_2$
- We write $g \supseteq_U f$ for "$g \supseteq f$ and $Dom(g) = Dom(f) \cup U$"

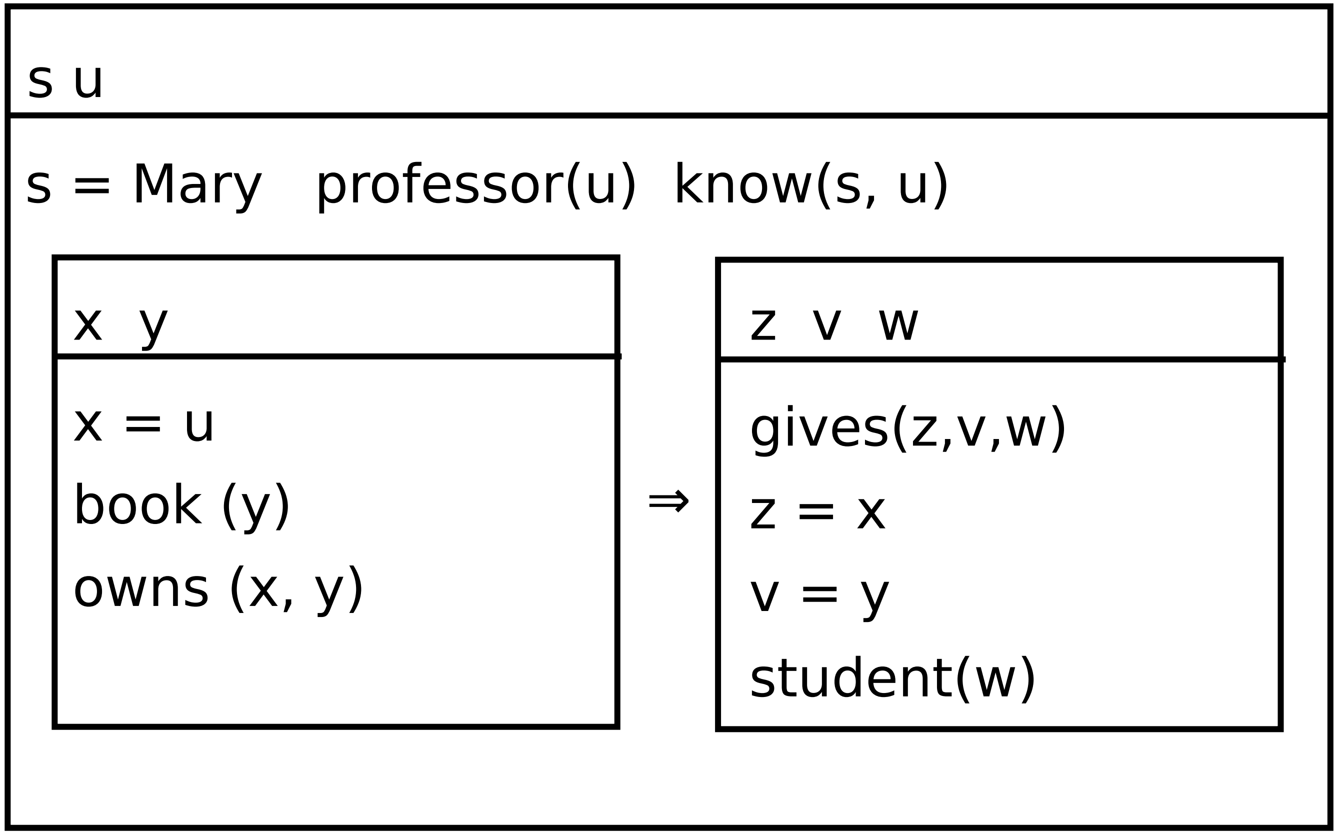
This seems to work ...

If a professor owns a book, he reads it.



... but in the general case, it doensn‘t

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



Verifying embedding for Duplex Conditions

- **$f \models_M K1 \Rightarrow K2$** iff

  for all $g \supseteq_{U_{K1}} f$ such that $g \models_M K_1$,

  there is a $h \supseteq_{U_{K2}} g$ such that $h \models_M K_2$

Embedding (Revised)

- 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: 1st Extension

- 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)	$\mathbf{f \models_M K_1 \Rightarrow K_2}$	iff	for all $g \supseteq_{U_{K1}} f$ such that $g \models_M K_1$, there is a $h \supseteq_{U_{K2}} g$ such that $h \models_M K_2$

Definition of Truth, Revised

- 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.**

Construction Rule for Universal NPs

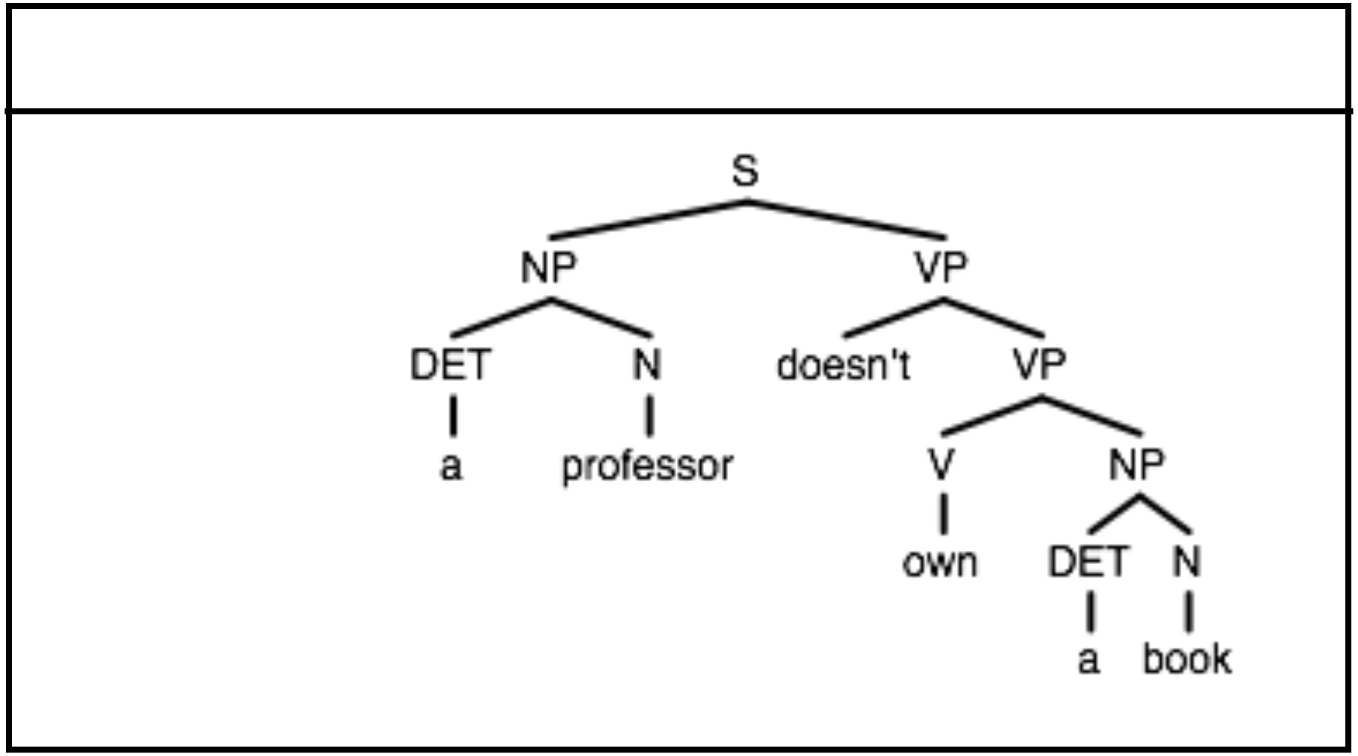
- **Triggering configuration:**
  - α is a reducible condition in DRS K; α contains a subtree $[_S\ [_{NP}\ \beta]\ [_{VP}\ \gamma]]$ or $[_{VP}\ [_V\ \gamma]\ [_{NP}\ \beta]]$
  - β = every δ
- **Action:**
  - Remove α from CK.
  - Add $K_1 \Rightarrow K_2$ to C_K, where
    - $K_1 = \langle \{x\},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

Construction Rule for Negation

- **Triggering configuration:**
  - α is a reducible condition in DRS K of the form $[_S\ \beta\ [_{VP}\ \text{doesn't}\ [_{VP}\ \gamma]]]$
- **Action:**
  - Remove α from C_K
  - Add $\neg K_1$ to C_K, where $K_1 = \langle \emptyset, \{\ [_S\ \beta\ [_{VP}\ \gamma]]\ \} \rangle$

Negation: Example

- *A professor doesn’t own a book.*

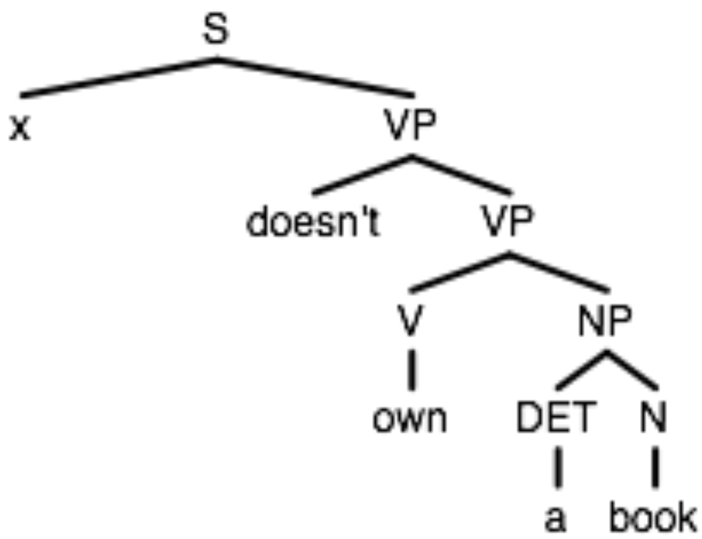


Negation: Example

- *A professor doesn’t own a book.*

x

professor(x)



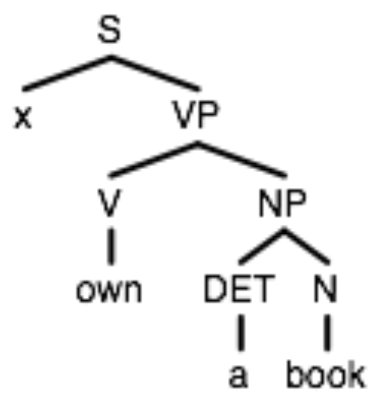
Negation: Example

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

x

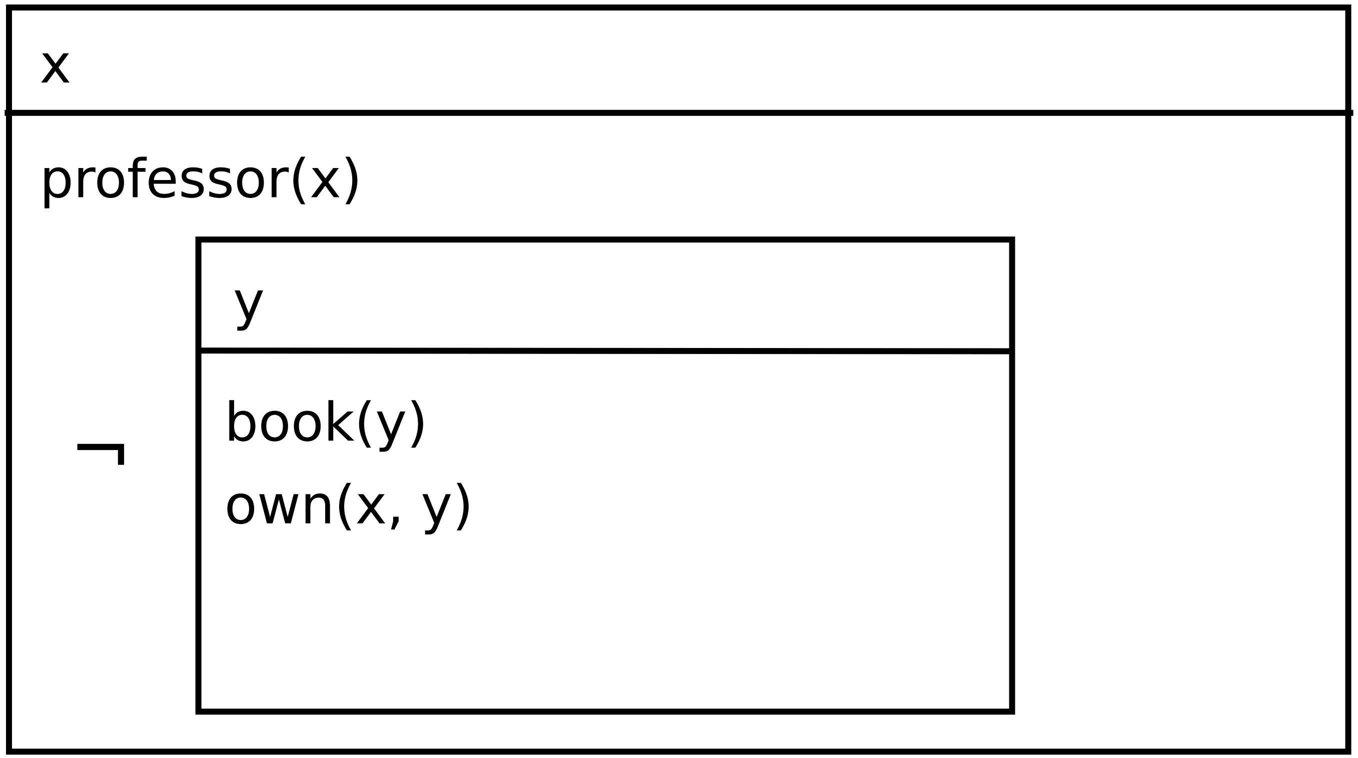
professor(x)

¬



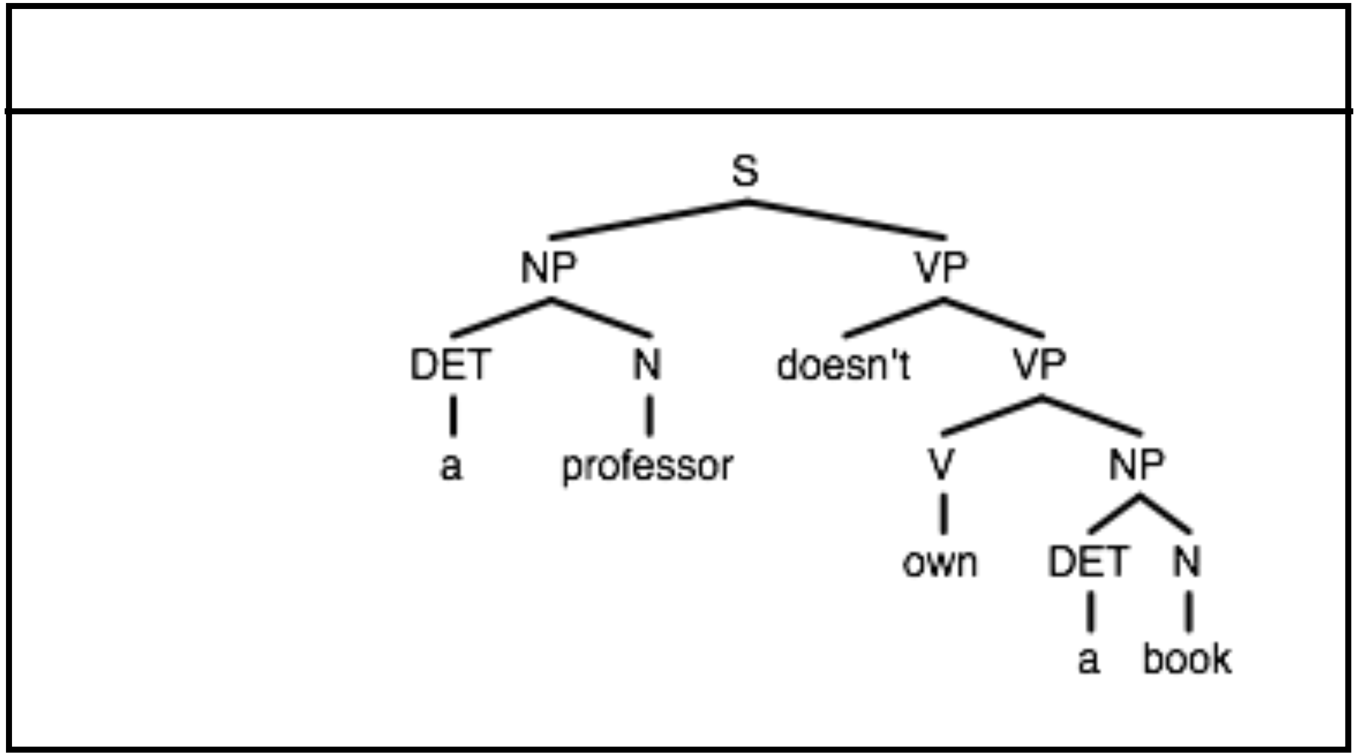
Negation: Example

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



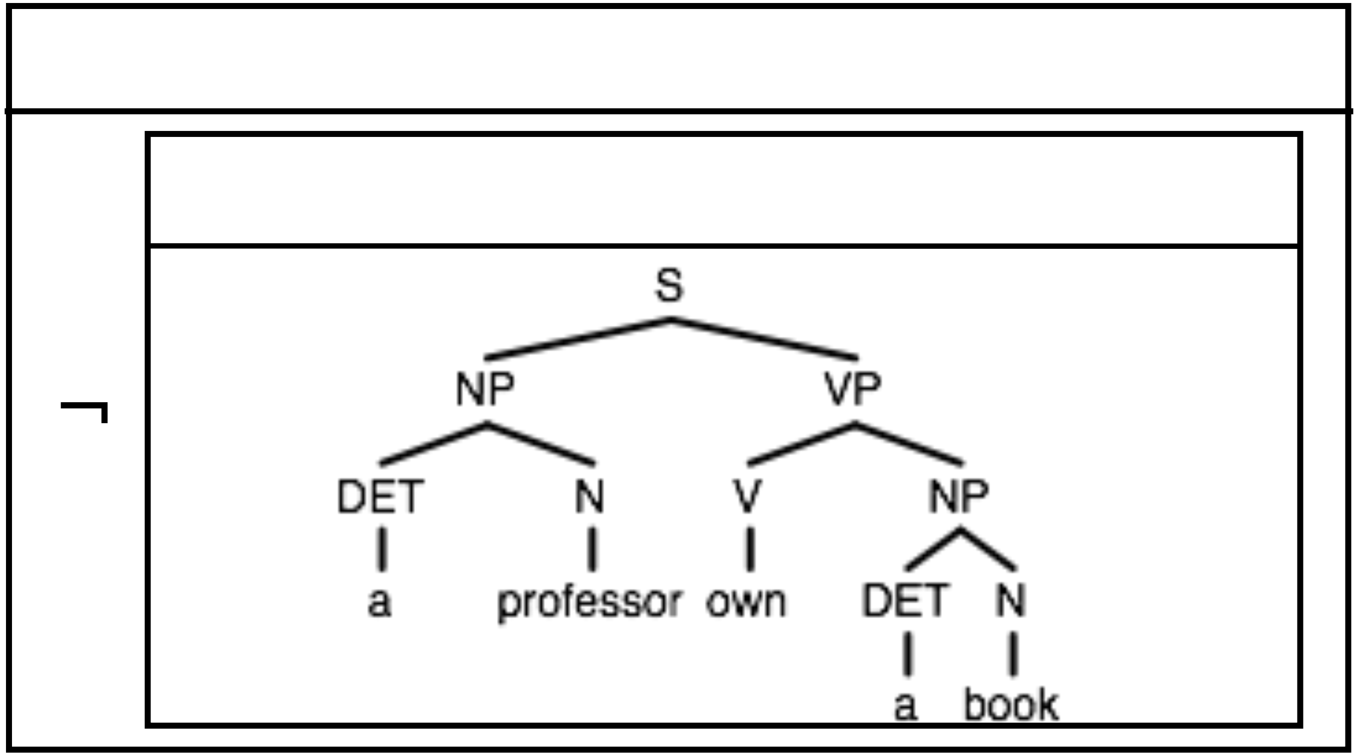
Negation: Example, 2nd Reading

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



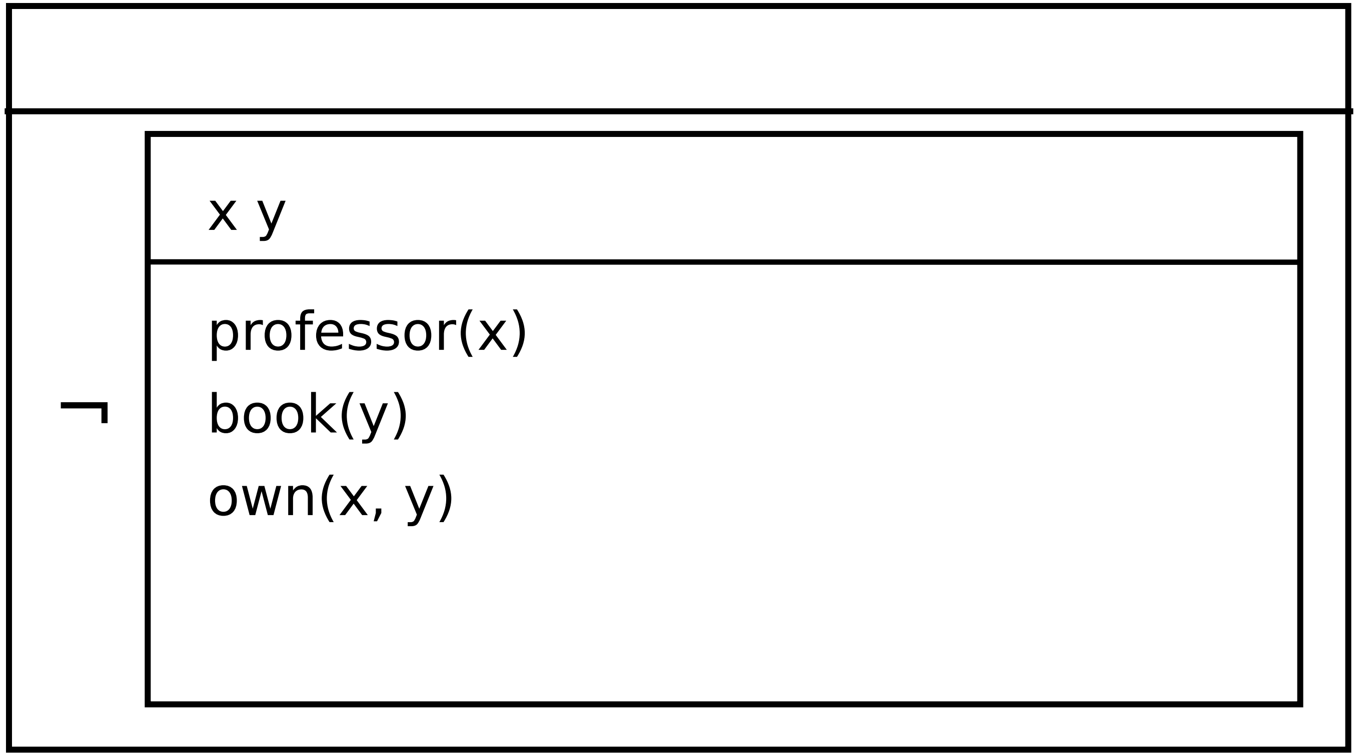
Negation: Example, 2nd Reading

- *A professor doesn’t own a book.*



Negation: Example, 2nd Reading

- *A professor doesn’t own a book.*

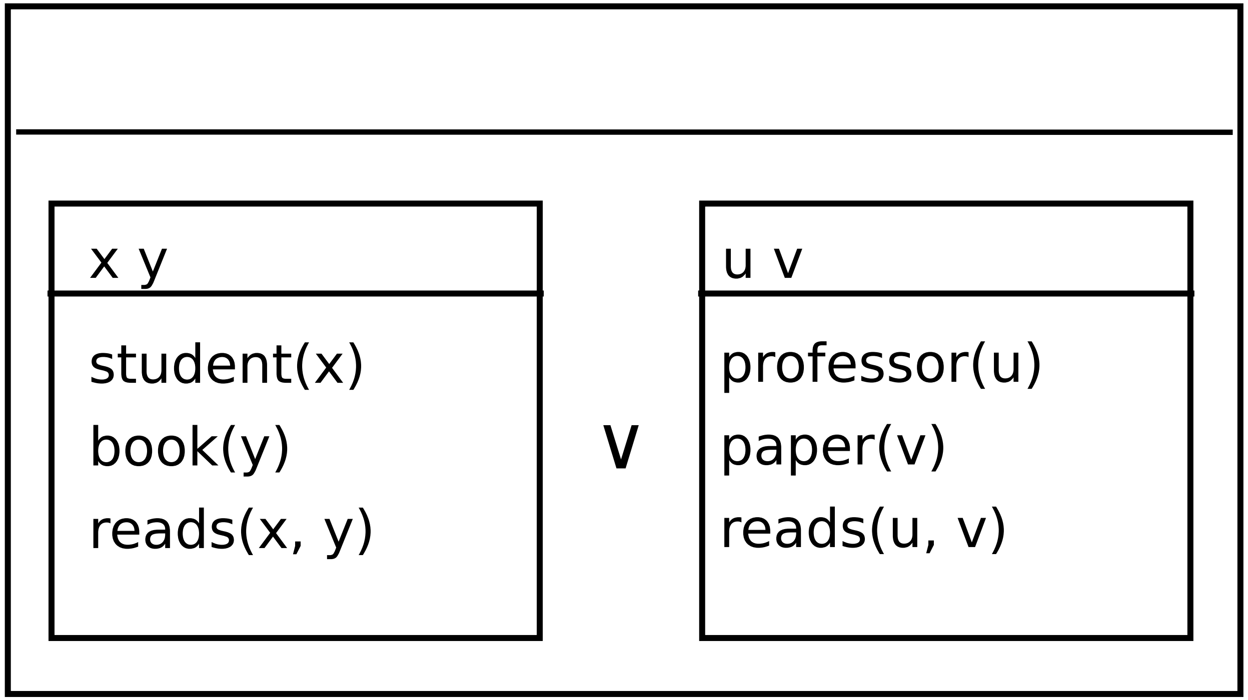


Construction rule for clausal disjunction

- **Triggering configuration:**
  - α is a reducible condition in DRS K of the form $[_S\ [_S\ \beta]\ \text{or}\ [_S\ \gamma]]$
- **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.*



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 and K_2 DRSs
  - $\neg K_1$ — K_1 DRS

Verifying Embedding: 2nd Extension

- 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) $f \models M\ K1 \Rightarrow K2$ iff for all $g \supseteq_{U_{K1}} f$ such that $g \models_M K_1$, there is a $h \supseteq_{U_{K2}} g$ such that $h \models_M K_2$

  (v) $\mathbf{f \models_M K_1 \vee K_2}$ iff there is a $g_1 \supseteq_{U_{K1}} f$ such that $g_1 \models_M K_1$ or there is a $g_2 \supseteq_{U_{K2}} f$ such that $g_2 \models_M K_2$

  (vi) $\mathbf{f \models_M \neg K_1}$ iff there is no $g \supseteq_{U_{K1}} f$ such that $g \models_M K_1$