Exceptional Scope as Scopal Independence

Adrian Brasoveanu, Donka F. Farkas — UC Santa Cruz
abrsvn,farkas@ucsc.edu

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1 Introduction and Data

The essence of scope in natural language semantics:

- does the interpretation of an expression e_1 affect the interpretation of another expression e_2 or not?

(1) Every^x student in my class read a^y paper about scope.

How can we tell whether interpretation of $\mathbf{Q}y$ (*a paper about scope*) was affected by $\mathbf{Q}x$ (*every student*)?[1]

- $\mathbf{Q}y$ is in the scope of $\mathbf{Q}x$: y may co-vary with x
- $\mathbf{Q}y$ is outside the scope of $\mathbf{Q}x$: y's value is fixed relative to x

Question 1: Dependence or independence?

Two possible conceptualizations:

(i) dependence-based approach: establish which quantifier(s) $\mathbf{Q}y$ is *dependent* on

(ii) independence-based approach: establish which quantifier(s) $\mathbf{Q}y$ is *independent* of

Logic has taken both paths. N(atural) L(anguage) semantics has only followed (i).

Our answer to Question 1

There are advantages to following (ii) and thus to importing the main insight from (in)dependence-friendly logic into NL semantics.

[1] In this talk we deal only with cases where the two expressions are quantifiers and moreover, one is an indefinite.

Question 2: Syntax or semantics or both?

NL semantics followed the lead of FOL in treating scope as a syntactic matter; scopal relations are determined at the combinatorial level.

(i) semantic scope is determined by NL syntax if syntax is the only source of constraints on meaning composition

(ii) scope is determined by both NL syntax and NL semantics if semantics contributes its own constraints on meaning composition

Compositional semantics of (1) yields the (equivalent of the) two FOL translations in (2) and (3):

(2) $\forall x[\text{STUDENT}(x)]\ (\exists y[\text{PAPER}(y)]\ (\text{READ}(x, y)))$

(3) $\exists y[\text{PAPER}(y)]\ (\forall x[\text{STUDENT}(x)]\ (\text{READ}(x, y)))$

Well-known problem 1

Contrast between indefinites and universals (Farkas 1981, Fodor & Sag 1982, Abusch 1994 among many others):

(i) indefinites enjoy free upward scope – disregarding not only clausal but also island boundaries

(4) Every^x student read every^y paper that a^z professor recommended.

- the indefinite may scope over the first universal or over both in (4) – hence, three possible readings depending on relation between the indefinite and each universal

(ii) the upward scope of universals is clause-bounded

(5) John read a^x paper that every^y professor recommended.

- the universal cannot scope over the indefinite

Lesson 1

The scopal freedom of indefinites is problematic for syntax-based accounts. This type of freedom is similar to anaphoric relations (because it is syntactically non-local), but we should resist the temptation of treating them alike because the constraints on the two phenomena are different (e.g., WCO effects for pronouns, but not for inverse scope).

Well-known problem 2

Scope of indefinites obeys two syntactic constraints:

- an indefinite cannot take scope over a quantifier **Q** without taking scope over everything below that quantifier

(6) Most^x students noticed that every^y professor recommended a^z paper about scope.

Missing reading:

(7) for every professor,
  there is a paper such that
    most students
      noticed that the professor recommended the paper

Thus: *a*^{z} *paper* cannot scope over *most*^{x} *students*, but under *every*^{y} *professor*.

(8) *No Skipping Constraint*: If an indefinite is independent relative to a quantifier **Q**, it is independent relative to all quantifiers **Q**′ that are in the syntactic scope of **Q**.

- an indefinite with a bound variable in its restrictor cannot outscope the binder of that variable (Abusch 1994, Chierchia 2001, Schwarz 2001)

(9) Every^x student read every^y paper that one^z of its$_y$ authors recommended.

The indefinite *one*^{z} *of its*$_y$ *authors* can have only narrowest scope.

(10) *Binder Roof Constraint*: an indefinite cannot scope over a quantifier that binds into its restrictor.

Lesson 2

Configurational matters cannot be disregarded altogether.

Our answer to Question 2

Both syntax and semantics, in the following ways:

- *syntax* constrains the order in which *bona fide* quantifiers are interpreted and the *semantics* of indefinites says that they can scope upward only relative to this particular order – hence: no skipping

- the *semantics* of indefinites says that the semantic scope of the existential quantifier contributed by indefinites and the semantic scope of its restrictor formula are the same – hence: binders block upward scope

The issue

How to capture both the exceptional freedom that the scope of indefinites exhibits and the syntactic constraints on this freedom.

2 Outline of Proposal

- interpret indefinites *in situ* – i.e., we are partially divorcing semantic scope from configurational matters (see Steedman 2007, Farkas 1997)

- depart from previous linguistic accounts in conceptualizing scope as a matter of *independence* by marking when the interpretation of an expression must be *rigid* (invariant) relative to another

- main role of syntactic structure: if a quantifier $\mathbf{Q}x$ structurally commands a quantifier $\mathbf{Q}'y$, x becomes available for y to potentially covary with or be independent of

- the formalization of scopal (in)dependence is different from the formalization of referential dependencies because we work with variable sequences that we manipulate without making reference to particular variables in the sequence (in contrast, referential dependencies are captured by variable coindexation)

- consequently, scopal dependence is different from pronoun binding and scopal freedom is different from the referential freedom of deictic / anaphoric pronouns

An existential:

- accesses the *sequence* of variables contributed by the quantifiers previously evaluated (under a strictly syntactic theory of quantifier scope, these are the quantifiers c-commanding the existential at LF)

– the sequence $\langle x_1, \ldots, x_n \rangle$ contributed by the sequence of quantifiers $\mathbf{Q}_1, \ldots, \mathbf{Q}_n$, where $\mathbf{Q}_1$ is evaluated before $\mathbf{Q}_2$, $\mathbf{Q}_2$ before $\mathbf{Q}_3$ etc.

- breaks this sequence into two subsequences, a left one and a right one
  - choose a position m in the sequence of variables $\underset{\leftarrow m \rightarrow}{\langle x_1, \ldots, x_n \rangle}$ – and break it into the subsequences $\langle x_1, \ldots, x_m \rangle$ and $\langle x_{m+1}, \ldots, x_n \rangle$
- specifies that the witness contributed by the existential is *independent* of the values of the variables in the right subsequence
  - the witness is chosen in such a way that it is invariant relative to the values of the variables $x_{m+1}, \ldots, x_n$

Comparison with choice/Skolem-function approaches

- similarity: witness choice is the essence of existential interpretation
- difference: witness choice is connected to specification of *independence* relative to some sequence of variables

Example

(11) Every^x professor recommended every^y paper to a^z student.

(12) $\forall x[\text{PROFESSOR}(x)]$
$\quad(\forall y[\text{PAPER}(y)]$
$\qquad(\exists z[\text{STUDENT}(z)]$
$\qquad\quad(\text{RECOMMEND-TO}(x, y, z))))$

Assume:

- the set of professors x is $\{\alpha_1, \alpha_2\}$
- the set of papers y is $\{\beta_1, \beta_2\}$

The existential $\exists z$ chooses a witness that satisfies its restrictor $\text{STUDENT}(z)$ and its nuclear scope $\text{RECOMMEND-TO}(x, y, z)$.
Given that the sequence of variables contributed by previously evaluated quantifiers is $\langle x, y \rangle$, this choice can happen in one of the following three ways:

(13)

Narrowest scope (NS):	subsequences: $\langle x, y \rangle$ and $\langle\rangle$ z is fixed relative to no variable, i.e., z (possibly) covaries with both x and y
Intermediate scope (IS):	subsequences: $\langle x \rangle$ and $\langle y \rangle$ z is fixed relative to y and (possibly) covaries with x
Widest scope (WS):	subsequences: $\langle\rangle$ and $\langle x, y \rangle$ z is fixed relative to both x and y

Scope depicted by matrices:

(14)

NS

x	y	z
α_1	β_1	γ
α_1	β_2	γ'
α_2	β_1	γ''
α_2	β_2	γ'''

IS

<table>
<tr><th>x</th><th>y</th><th>z</th></tr>
<tr><td>α_1</td><td>β_1</td><td rowspan="2">γ</td></tr>
<tr><td>α_1</td><td>β_2</td></tr>
<tr><td>α_2</td><td>β_1</td><td rowspan="2">γ'</td></tr>
<tr><td>α_2</td><td>β_2</td></tr>
</table>

WS

<table>
<tr><th>x</th><th>y</th><th>z</th></tr>
<tr><td>α_1</td><td>β_1</td><td rowspan="4">γ</td></tr>
<tr><td>α_1</td><td>β_2</td></tr>
<tr><td>α_2</td><td>β_1</td></tr>
<tr><td>α_2</td><td>β_2</td></tr>
</table>

Role of syntax: syntactic scope of the universals determines how one fixes the values of the witness of the existential.
Impossible IS: z is fixed relative to x, but covarying relative to y.
This is impossible because the sequence $\langle x, y \rangle$ cannot be broken into a left subsequence $\langle y \rangle$ and a right subsequence $\langle x \rangle$.

(15)

Disallowed IS

x	y	z
α_1	β_1	γ
α_1	β_2	γ'
α_2	β_1	γ
α_2	β_2	γ'

Disallowed IS (rows reordered)

<table>
<tr><th>x</th><th>y</th><th>z</th></tr>
<tr><td>α_1</td><td>β_1</td><td rowspan="2">γ</td></tr>
<tr><td>α_2</td><td>β_1</td></tr>
<tr><td>α_1</td><td>β_2</td><td rowspan="2">γ'</td></tr>
<tr><td>α_2</td><td>β_2</td></tr>
</table>

Questions to be addressed below:

- how should such matrices be formalized?
- how should we treat the non-variation requirement that may be contributed by the existential?

3 Scope in First-Order Logic with Choice (C-FOL)

Two formal novelties in the semantics

(i) formulas are evaluated relative to *sets* of assignments $G, G', \ldots$ (instead of single assignments $g, g', \ldots$) (see Hodges 1997,Väänänen 2007)

  – the interpretation function has the form $[\![\cdot]\!]^{\mathfrak{M},G}$

(ii) the index of evaluation for a quantifier contains the sequence $\langle x_1, \ldots, x_n \rangle$ of variables introduced by the previously evaluated (i.e., syntactically higher) quantifiers (in the spirit of Steedman 2007; see also Bittner 2003 and Schlenker 2005 among others for related proposals)

  – the interpretation function has the form $[\![\cdot]\!]^{\mathfrak{M},G,\langle x_1,\ldots,x_n \rangle}$

Use of sets of assignments

A set of total assignments G:

(16)

G	$\ldots$	x	y	z	$\ldots$
g_1	$\ldots$	$\alpha_1\ (= g_1(x))$	$\beta_1\ (= g_1(y))$	$\gamma_1\ (= g_1(z))$	$\ldots$
g_2	$\ldots$	$\alpha_2\ (= g_2(x))$	$\beta_2\ (= g_2(y))$	$\gamma_2\ (= g_2(z))$	$\ldots$
g_3	$\ldots$	$\alpha_3\ (= g_3(x))$	$\beta_3\ (= g_3(y))$	$\gamma_3\ (= g_3(z))$	$\ldots$
$\ldots$	$\ldots$	$\ldots$	$\ldots$	$\ldots$	$\ldots$

- independence of $\mathbf{Q}''z$ from $\mathbf{Q}'y$: z has to have a fixed value relative to the (possibly) varying values of y

(17) Fixed value condition (basic version): for all $g, g' \in G$, $g(z) = g'(z)$.

- if z does not covary with y, this means that:
  - $\mathbf{Q}''z$ is not in the *semantic* scope of $\mathbf{Q}'y$ (although it may well be in its *syntactic* scope)
- $\mathbf{Q}x$ may take both syntactic and semantic scope over $\mathbf{Q}''z$ (intermediate scope (IS) in (14)): value of z is fixed relative to y, but may covary with x

So, we need to be able to relativize the fixed value condition for z to the variable x.

(18) Fixed value condition (relativized version):
for all $g, g' \in G$, if $g(x) = g'(x)$, then $g(z) = g'(z)$.

(19)

x	y	z
α_1	β_1	γ
α_1	β_2	
α_2	β_1	γ'
α_2	β_2	

Use of sequence of variables as indices on set of assignment functions

- index of evaluation contains the sequence $\langle x_1, \ldots, x_n\rangle$ of variables introduced by the previous / higher quantifiers in the order of introduction
- these are the variables an existential *could* covary with
- existentials fix their semantic scope by choosing a position m in the sequence $\langle x_1, \ldots, x_n\rangle$
  - $\langle x_1, \ldots, x_n\rangle$
    $\leftarrow m \rightarrow$
- two subsequences:
  - left subsequence $\langle x_1, \ldots, x_m\rangle$ stores the variables that the indefinite possibly covaries with
  - right subsequence $\langle x_{m+1}, \ldots, x_n\rangle$ stores the variables relative to which the indefinite does *not* vary
- the C in our C-FOL stands for this choice

(20) An indefinite that is in the syntactic scope of a quantifier binding a variable x_n is in its semantic scope iff x_n is in the first sequence of variables.

Empirical predictions

(i) an indefinite may be within the semantic scope of a quantifier $\mathbf{Q}x$ only if $\mathbf{Q}x$ has syntactic scope over that indefinite (more generally: only if the semantic composition makes it so that the quantifier $\mathbf{Q}x$ is evaluated before the indefinite)

(ii) an indefinite may in principle be outside the semantic scope of a quantifier that takes syntactic scope over it

3.1 Existentials in C-FOL

Choice in existential quantification: superscript m targeting current sequence of variables $\langle x_1, \ldots, x_n\rangle$ contributed by the previous / higher quantifiers:

(21) $[\![\exists^m x[\phi]\ (\psi)]\!]^{\mathfrak{M},G,\langle x_1,\ldots,x_n\rangle} = \mathbb{T}$ iff

a. $0 \leq m \leq n$

b. $[\![\psi]\!]^{\mathfrak{M},G',\langle x_1,\ldots,x_n,x\rangle} = \mathbb{T}$, for some G' such that:

$$\text{i. if } m = 0\text{:} \begin{cases} G'[x]G \\ g(x) = g'(x),\ \text{for all } g, g' \in G' \\ [\![\phi]\!]^{\mathfrak{M},G',\langle x\rangle} = \mathbb{T} \end{cases}$$

$$\text{ii. if } m \neq 0\text{:} \begin{cases} G'[x]G \\ g(x) = g'(x),\ \text{for all } g, g' \in G' \\ \quad \text{that are ``}x_1, \ldots, x_m\text{''-identical,} \\ \quad \text{i.e., such that } g(x_1) = g'(x_1), \ldots, g(x_m) = g'(x_m) \\ [\![\phi]\!]^{\mathfrak{M},G',\langle x_1,\ldots,x_m,x\rangle} = \mathbb{T} \end{cases}$$

- $m = 0$: value of the existential is fixed (widest scope) in the absolute terms of (17)
- $m \neq 0$: value fixed relative to $\langle x_{m+1}, \ldots, x_n\rangle$ in the relativized terms of (18)

3.2 Deriving Syntactic Constraints on Scope

Universals in C-FOL

The basic idea:

- the nuclear scope is evaluated relative to the set of *all* g' that satisfy the restrictor
- collect in G' all g' that satisfy ϕ and evaluate ψ relative to G'

The basic formalization (see the appendix for more details):

(22) $[\![\forall x[\phi]\ (\psi)]\!]^{\mathfrak{M},G,\langle x_1,\ldots,x_n\rangle} = \mathbb{T}$ iff $[\![\psi]\!]^{\mathfrak{M},G',\langle x_1,\ldots,x_n,x\rangle} = \mathbb{T}$, where G' is the maximal set of assignments that satisfies ϕ relative to x, G and $\langle x_1,\ldots,x_n\rangle$.

Existentials in the scope of universals – a simple example

(23) Every^x student read a^y paper.

(24) $\forall x[\text{STUDENT}(x)]\ (\exists^0 y[\text{PAPER}(y)]\ (\text{READ}(x,y)))$

(25) $\forall x[\text{STUDENT}(x)]\ (\exists^1 y[\text{PAPER}(y)]\ (\text{READ}(x,y)))$

- superscript 0: wide scope for the indefinite
- superscript 1: narrow scope for the indefinite

Interpretation relative to an arbitrary G and the empty sequence of variables $\langle\rangle$:

(26) Truth: a formula ϕ is true in model $\mathfrak{M}$ iff $[\![\phi]\!]^{\mathfrak{M},G,\langle\rangle} = \mathbb{T}$ for any set of assignments G, where $\langle\rangle$ is the empty sequence of variables.

Assume that the set of students in $\mathfrak{M}$ is $\{stud_1, stud_2, stud_3\}$.

(i) $\forall x[\text{STUDENT}(x)]$ introduces the set of all students relative to the variable x and relative to each assignment $g \in G$

(ii) $\exists^{0/1} y[\text{PAPER}(y)]$ introduces a paper that is the same for every student (if the choice for superscript is 0) or possibly different from student to student (if the superscript choice is 1)

(iii) each assignment in the resulting set should be such that the x-student in that assignment read the y-paper in that assignment.

(27)

...	...	...	...
...	...	...	...

$\xRightarrow{\forall x[\text{STUDENT}(x)]}$

...	x	...	...
...	$stud_1$	...	...
...	$stud_2$	...	...
...	$stud_3$	...	...

$\xRightarrow{\exists^0 y[\text{PAPER}(y)]}$

...	x	y	...
...	$stud_1$	*paper*	...
...	$stud_2$		...
...	$stud_3$		...

$\xRightarrow{\text{READ}(x,y)}$ $stud_1$ read *paper*; $stud_2$ read *paper*; $stud_3$ read *paper*

$\xRightarrow{\exists^1 y[\text{PAPER}(y)]}$

...	x	y	...
...	$stud_1$	*paper*	...
...	$stud_2$	*paper*$'$	...
...	$stud_3$	*paper*$''$	...

$\xRightarrow{\text{READ}(x,y)}$ $stud_1$ read *paper*; $stud_2$ read *paper*$'$; $stud_3$ read *paper*$''$

Syntactic sensitivity of indefinite scope

Capturing the No Skipping Constraint (8)

- independence (wide scope) is established relative to the *sequence of previously introduced variables*, whose order parallels the syntactic scope of quantifiers
- the subscript breaks this sequence of variables into two sequences – it does *not* choose a variable in the sequence to be syntactically coindexed with (and therefore dependent on or independent of)

Capturing the Binder Roof Constraint (10)

- by (7), the restrictor of an indefinite is interpreted relative to the variables that the indefinite possibly depends on: the restrictor of an existential $\exists^m$ is interpreted relative to the sequence of variables $\langle x_1,\ldots,x_m\rangle$
- thus: the semantic scope of the restrictor ϕ is the same as the semantic scope of the existential $\exists^m$

3.3 Deriving Exceptional Scope

(28) Every^x student read every^y paper that a^z professor recommended.

WS, IS and NS: choice of superscript fixed to 0, 1 or 2, respectively (no other choices are possible relative to the sequence of variables $\langle x, y\rangle$).

(29) $\forall x[\text{STUDENT}(x)]$
$(\forall y[\text{PAPER}(y) \wedge$
$\exists^{0/1/2} z[\text{PROFESSOR}(z)]\ (\text{RECOMMEND}(z,y))]$
$(\text{READ}(x,y)))$

IS reading (superscript=1): for each student x, we choose a professor z and require x to have read every paper that z recommended.

4 Conclusion

(i) formulas evaluated relative to set of assignments and sequence of variables whose order is syntactically determined

(ii) existentials are interpreted *in situ*

(iii) semantic scope of existentials is a matter of index of evaluation

(iv) more specifically: semantic scope is a matter of independence relative to a sequence of previously introduced variables

(v) scope of indefinites: break its variable sequence at some position m signaling fixed value relative to variables after the m^{th} position

Consequences:

(vi) existentials have free upward scope limited by the 'no skipping' and the 'binder roof' constraints

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Appendix – The Formal System: First-Order Logic with Choice (C-FOL)

The Basics

- the usual models (just like in FOL): $\mathfrak{M} = \langle \mathfrak{D}, \mathfrak{I} \rangle$
  - $\mathfrak{D}$ – the domain of individuals
  - $\mathfrak{I}$ – the basic interpretation function
- an $\mathfrak{M}$-assignment g for C-FOL is a total function from the set of variables $\mathcal{V}$ to $\mathfrak{D}$ (just like in FOL)

Quantification in FOL: pointwise (i.e., variablewise) manipulation of variable assignments, abbreviated as $g'[x]g$.

(1) $g'[x]g :=$ for all variables $v \in \mathcal{V}$, if $v \neq x$, then $g'(v) = g(v)$

- FOL existential: $[\![\exists x \ldots]\!]^{\mathfrak{M},g} = \mathbb{T}$ iff for some assignment g' s.t. $g'[x]g, \ldots$
- FOL universal: $[\![\forall x \ldots]\!]^{\mathfrak{M},g} = \mathbb{T}$ iff for any assignment g' s.t. $g'[x]g, \ldots$

In C-FOL – we need to generalize to sets of assignments $G'[x]G$:

(2) $$G'[x]G := \begin{cases} \text{for all } g' \in G', \text{ there is a } g \in G \text{ such that } g'[x]g \\ \text{for all } g \in G, \text{ there is a } g' \in G' \text{ such that } g'[x]g \end{cases}$$

Atomic formulas

(3) $[\![R(x_{i_1}, \ldots, x_{i_{n'}})]\!]^{\mathfrak{M},G,\langle x_1,\ldots,x_n \rangle} = \mathbb{T}$ iff
  a. $\{x_{i_1}, \ldots, x_{i_{n'}}\} \subseteq \{x_1, \ldots, x_n\}$
  b. $G \neq \emptyset$
  c. $\langle g(x_{i_1}), \ldots, g(x_{i_{n'}}) \rangle \in \mathfrak{I}(R)$, for all $g \in G$

- (3a) bans free variables
- (3c) says that the set of assignments G satisfies an atomic formula $R(x_{i_1}, \ldots, x_{i_{n'}})$ if each assignment $g \in G$ satisfies it
- (3b) rules out the case in which G vacuously satisfies $R(x_{i_1}, \ldots, x_{i_{n'}})$

(4)

G	$\ldots$	x_{i_1}	$\ldots$	$x_{i_{n'}}$	$\ldots$
g_1	$\ldots$	α_1 $(= g_1(x_{i_1}))$	$\ldots$	$\alpha_{n'}$ $(= g_1(x_{i_{n'}}))$	$\ldots$
		$\langle \alpha_1, \ldots, \alpha_{n'} \rangle \in \mathfrak{I}(R)$			
g_2	$\ldots$	β_1 $(= g_2(x_{i_1}))$	$\ldots$	$\beta_{n'}$ $(= g_2(x_{i_{n'}}))$	$\ldots$
		$\langle \beta_1, \ldots, \beta_{n'} \rangle \in \mathfrak{I}(R)$			
g_3	$\ldots$	γ_1 $(= g_3(x_{i_1}))$	$\ldots$	$\gamma_{n'}$ $(= g_3(x_{i_{n'}}))$	$\ldots$
		$\langle \gamma_1, \ldots, \gamma_{n'} \rangle \in \mathfrak{I}(R)$			
$\ldots$	$\ldots$	$\ldots$	$\ldots$	$\ldots$	$\ldots$

Representation of a set of assignments:

(5)

$\ldots$	x_{i_1}	$\ldots$	$x_{i_{n'}}$	$\ldots$
$\ldots$	α_1	$\ldots$	$\alpha_{n'}$	$\ldots$
$\ldots$	β_1	$\ldots$	$\beta_{n'}$	$\ldots$
$\ldots$	γ_1	$\ldots$	$\gamma_{n'}$	$\ldots$
$\ldots$	$\ldots$	$\ldots$	$\ldots$	$\ldots$

Conjunction

(6) $[\![\phi \wedge \psi]\!]^{\mathfrak{M},G,\langle x_1,\ldots,x_n \rangle} = \mathbb{T}$ iff
  a. $[\![\phi]\!]^{\mathfrak{M},G,\langle x_1,\ldots,x_n \rangle} = \mathbb{T}$
  b. $[\![\psi]\!]^{\mathfrak{M},G,\langle x_1,\ldots,x_n \rangle} = \mathbb{T}$

Existential Quantification

Choice in existential quantification: superscript m targeting current sequence of variables $\langle x_1, \ldots, x_n \rangle$ contributed by the previous / higher quantifiers:

(7) $[\![\exists^m x[\phi]\ (\psi)]\!]^{\mathfrak{M},G,\langle x_1,\ldots,x_n \rangle} = \mathbb{T}$ iff

a. $0 \leq m \leq n$

b. $[\![\psi]\!]^{\mathfrak{M},G',\langle x_1,\ldots,x_n,x\rangle} = \mathbb{T}$, for some G' such that:

i. if $m = 0$: $\begin{cases} G'[x]G \\ g(x) = g'(x), \text{ for all } g, g' \in G' \\ [\![\phi]\!]^{\mathfrak{M},G',\langle x\rangle} = \mathbb{T} \end{cases}$

ii. if $m \neq 0$: $\begin{cases} G'[x]G \\ g(x) = g'(x), \text{ for all } g, g' \in G' \\ \quad \text{that are ``}x_1,\ldots,x_m\text{''-identical,} \\ \quad \text{i.e., such that } g(x_1) = g'(x_1),\ldots,g(x_m) = g'(x_m) \\ [\![\phi]\!]^{\mathfrak{M},G',\langle x_1,\ldots,x_m,x\rangle} = \mathbb{T} \end{cases}$

Universal Quantification

Preliminary version

Simpler because we disregard existentials in the restrictor of universals. We can use it to show how the syntactic constraints on the scope of indefinites are derived, but it makes incorrect predictions for exceptional scope cases.

- the nuclear scope is evaluated relative to the set of *all* g' that satisfy the restrictor
- collect in G' all g' that satisfy ϕ and evaluate ψ relative to G'

(8) $[\![\forall x[\phi]\ (\psi)]\!]^{\mathfrak{M},G,\langle x_1,\ldots,x_n\rangle} = \mathbb{T}$ iff $[\![\psi]\!]^{\mathfrak{M},G',\langle x_1,\ldots,x_n,x\rangle} = \mathbb{T}$, where G' is the maximal set of assignments that satisfies ϕ relative to x, G and $\langle x_1,\ldots,x_n\rangle$.

(9) G' is the maximal set of assignments that satisfies ϕ relative to the variable x, the set of assignments G and the sequence of variables $\langle x_1,\ldots,x_n\rangle$ iff $G' = \bigcup_{g\in G}\left\{g' : g'[x]g \text{ and } [\![\phi]\!]^{\mathfrak{M},\{g'\},\langle x_1,\ldots,x_n,x\rangle} = \mathbb{T}\right\}$.

Final version

Problem with the preliminary definition of universals in (8):

- when evaluating the restrictor of $\forall y[\text{PAPER}(y) \wedge \exists^1 z[\text{PROFESSOR}(z)]$ in our exceptional scope example in (4), we lack access to the entire previous set of assignments that stores all the x-students
- assignments are evaluated one at a time so we cannot ensure that a single z-professor is chosen for each x-student
- we basically collapse the IS (or WS) reading into the NS reading

Fixing the problem: modify the interpretation of the universal.

(10) $[\![\forall x[\phi]\ (\psi)]\!]^{\mathfrak{M},G,\langle x_1,\ldots,x_n\rangle} = \mathbb{T}$ iff $[\![\psi]\!]^{\mathfrak{M},G',\langle x_1,\ldots,x_n,x\rangle} = \mathbb{T}$, for some G' that is a maximal set of assignments relative to x, ϕ, G and $\langle x_1,\ldots,x_n\rangle$.

(11) G' is a maximal set of assignments relative to a variable x, a formula ϕ, a set of assignments G and a tuple of variables $\langle x_1,\ldots,x_n\rangle$ iff

a. $G'[x]G$

b. $[\![\phi]\!]^{\mathfrak{M},G',\langle x_1,\ldots,x_n,x\rangle} = \mathbb{T}$

c. there is no $G'' \neq G'$ such that $G' \subseteq G''$ and:

i. $G''[x]G$

ii. $[\![\phi]\!]^{\mathfrak{M},G'',\langle x_1,\ldots,x_n,x\rangle} = \mathbb{T}$

The main difference between (8) and (10):

- old way: restrictor ϕ is evaluated relative to each $g' \in G'$
- new way: restrictor ϕ is evaluated relative to G' as a whole

Truth

(12) A formula ϕ is true in model $\mathfrak{M}$ iff $[\![\phi]\!]^{\mathfrak{M},G,\langle\rangle} = \mathbb{T}$ for any set of assignments G, where $\langle\rangle$ is the empty sequence of variables.

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