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PREDICATE LOGIC WITH BARRIERS AND ITS LOCALITY EFFECTS

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Abstract

This paper presents a system of interpretation for a language of first order predicate logic with barriers (*PLB*), which builds on Dekker's (2002) Predicate Logic with Anaphora (*PLA*). The novel ingredient of the system is a barrier operator. This moves value information from the assignment function to the discourse context, with the result of producing locality effects. These are shown to match up with a range of locality effects found in natural language, including binding (condition A, B and C) effects, constraints on different types of movement (A-bar and A), and strong crossover violations.

1 Introduction

This paper presents a system of interpretation for a language of first order predicate logic with barriers (*PLB*), which builds on Dekker's (2002) Predicate Logic with Anaphora (*PLA*). The novel ingredient of the system is a barrier operator. This moves value information from the assignment function to the discourse context, with the result of producing locality effects. These are shown to match up with a range of locality effects found in natural language.

The paper is structured as follows. First we introduce *PLB*. Then we take a look at some of its properties. Then we show how *PLB* can be used in accounts of a range of natural language data involving locality effects, including binding relations (condition A, B and C effects), constraints on different types of movement (A-bar and A), and strong crossover violations.

2 Predicate Logic with Barriers

This section presents Predicate Logic with Barriers (*PLB*). This is a system of interpretation for a language of first order predicate logic with barriers that builds on Dekker's (2002) Predicate Logic with Anaphora (*PLA*). As a consequence, in addition to its own `[BAR]` operator, it inherits the syntax of predicate logic, and an additional category of terms that we will refer to as pointers $P = \{\mathrm{p}_1, \mathrm{p}_2, \ldots\}$.

The semantics of the system is stated as a Tarskian satisfaction relation between finite sequences of individuals and sentences, with the sequences providing intended referents for terms in the sentences. More specifically, term interpretation is relative to a model (M), a partial variable assignment (g) and a sequence ($\vec{e}$) of individuals from M's domain (e_i is the i-th individual of $\vec{e}$):

(1) $[\![c]\!]_{M,g,\vec{e}} = M(c) \qquad [\![x]\!]_{M,g,\vec{e}} = g(x) \qquad [\![\mathrm{p}_i]\!]_{M,g,\vec{e}} = e_i$

That is, constants take there denotation from the model, as is usual. Variables get their value from the current variable assignment. But since this is partial, it is possible for there to be no value. If such is the case, the evaluation is said to crash. A pointer p_i selects the i-th individual from the current $\vec{e}$ sequence, which is taken to provide the discourse context. As a consequence, it is made coreferential with the i-th potential antecedent in preceding discourse. If $\mathtt{p}_i$ is evaluated with respect to a sequence with length less than i, evaluation is once more said to crash. Hence, pointers can only be used in environments where the context supplies a suitable range of antecedents.

The rest of the semantics is spelled out in (2) by means of a satisfaction relation $\models$, which may hold between an ordinary first order model M with domain D, a partial variable assignment function (g) and two independent sequences of witnesses on the one hand and a formula ϕ on the other. Witnesses are elements from D. The two independent sequences are, respectively:

- the novel sequence—referred to as NS henceforth, and
- the familiar sequence or discourse context—referred to as FS henceforth.

(2)
$$
\begin{array}{ll}
M,g,\langle\rangle,\vec{e} \models Pt_1,\ldots,t_n & \text{iff } \langle [\![t_1]\!]_{M,g,\vec{e}},\ldots,[\![t_n]\!]_{M,g,\vec{e}}\rangle \in M(P) \\
M,g,\langle\rangle,\vec{e} \models \neg\phi & \text{iff } \neg\exists\vec{c}\in D^* : M,g,\vec{c},\vec{e} \models \phi \\
M,g,d\vec{c},\vec{e} \models \exists x\phi & \text{iff } M,g[x/d],\vec{c},\vec{e} \models \phi \\
M,g,\vec{c}\vec{a},\vec{e} \models \phi\wedge\psi & \text{iff } M,g,\vec{a},\vec{e} \models \phi \text{ and } M,g,\vec{c},\vec{a}\vec{e} \models \psi \\
M,g,\vec{c},\vec{e} \models \mathtt{[BAR}\backslash X\mathtt{]}\phi & \text{iff } M,\Downarrow(g,X),\vec{c},\Uparrow(g,X)+\vec{e} \models \phi
\end{array}
$$

Notation used:

- $\vec{c}+\vec{e}$ is the concatenation of sequences $\vec{c}$ and $\vec{e}$ (also abbreviated: $\vec{c}\vec{e}$);
- $d\vec{e}$ is a sequence with witness d as its first element;
- $\langle\rangle$ denotes the empty sequence;
- D^* is the set of all sequences made up of elements from D (the domain of the model);
- $\Downarrow(g,X)$ is the assignment g without assignments to variables not in X, e.g. $\Downarrow([x\mapsto a, y\mapsto b, z\mapsto c],\{y\}) = [y\mapsto b]$, which is the assignment that maps y to b, but no other variable to any other value; and
- $\Uparrow(g,X)$ is a sequence made up of the values g assigns to all its variables minus those in X, e.g. $\Uparrow([x\mapsto a, y\mapsto b, z\mapsto c],\{y\}) = \begin{cases} ac \\ ca \end{cases}$.

3 A closer look

In this section we focus on properties of the *PLB* system in (2).

3.1 Atomic formulae

Atomic formulae in (2) are evaluated in a Tarskian way relative to a model, an assignment function and an FS. One thing to note is that an atomic formula can only be evaluated if the NS is empty. If this condition is not met, evaluation is once more said to crash. This has the effect of helping to ensure that there are not too many witnesses present for the evaluation.

3.2 Negation

The negation of a formula ϕ tells us that there is no way of supporting ϕ. In so doing, it binds the existential quantifiers of the formula in its scope, so that, e.g. $\neg\exists x F(x)$, as usual, means that no x is F. In addition, negation requires that the NS is empty. If this is not the case, evaluation is once more said to crash. Again, this helps to ensure there are not too many witnesses present for the evaluation.

3.3 Existentials

An existential quantifier forms an instruction to remove the frontmost item of the NS and have it assigned to variable occurrences that the quantifier binds. This is standard quantifier behaviour, in the sense that variables are bound. But the whole action can also be seen as exhibiting the behaviour of a free variable, in the sense that the value imparted comes from a predetermined source, namely, the NS. We should also note that if $\exists x\phi$ is evaluated with respect to an empty NS, the satisfaction procedure crashes. This ensures that enough witnesses are present for the evaluation.

3.4 Formula length

Before going on to look at how conjunction works, it will be useful to have a function l for calculating the number of indefinites (existential quantifiers) in a formula that will take their value from the NS, or equivalently, the number of indefinites not in the scope of a negation in that formula. We we call $l(\phi)$ the length of a formula ϕ. It is defined as follows:

(3)
$$\begin{aligned}
l(Pt_1,\ldots,t_m) &= 0\\
l(\exists x\phi) &= l(\phi)+1\\
l(\neg\phi) &= 0\\
l(\phi\wedge\psi) &= l(\phi)+l(\psi)\\
l(\texttt{[BAR}\backslash X\texttt{]}\phi) &= l(\phi)
\end{aligned}$$

3.5 Dekker's conjunction

The system inherits its conjunction from Dekker's (2002) Predicate Logic with Anaphora. This realises the so-called 'dynamics of interpretation' familiar from Discourse Representation Theory (Kamp and Reyle, 1993): the first conjunct is evaluated before the second conjunct has come up with its possible witnesses and the second after the first has done so. More formally, if NS $\vec{a}$ satisfies ϕ given FS $\vec{e}$, and NS $\vec{c}$ satisfies a subsequent ψ given extended FS $\vec{a}\vec{e}$, then the combined NS $\vec{c}\vec{a}$ also satisfies the conjunction of ϕ and ψ given FS $\vec{e}$. This can be pictured as in (4), given that i is the length $l(\psi)$ of ψ to make $\langle c_1 ... c_i\rangle$ the equivalent of $\vec{c}$, and j is the length $l(\phi)$ of ϕ to make $\langle c_{i+1} ... c_{i+j}\rangle$ the equivalent of $\vec{a}$.

(4)
$$\begin{array}{llll} M, g, \langle c_1 ... c_i c_{i+1} ... c_{i+j}\rangle, \langle e_i ...\rangle & \models & \phi \wedge \psi & \text{iff} \\ M, g, \qquad \langle c_{i+1} ... c_{i+j}\rangle, \langle e_i ...\rangle & \models & \phi & \text{and} \\ M, g, \langle c_1 ... c_i\rangle, \langle c_{i+1} ... c_{i+j} e_i ...\rangle & \models & \quad \psi & \end{array}$$

As (4) suggests, we might think of the NS and FS as forming a single sequence that gets judiciously broken up by the interpretation procedure (as indeed Dekker (2002) does), since the ordering of items both inside and between the two sequences is always maintained.

The picture of (4) also clearly shows how the first conjunct is able to contribute its sequence of (possible) witnesses as accessible values for the pronouns of the second conjunct, since for the second conjunct these witnesses are at the front of the FS. This "dynamics" is further illustrated by (5), where *he* and *someone* must take their values from different witnesses, as illustrated by the semantic calculation in (6):

(5) He smiles and someone laughs. $[S\mathtt{p}_1 \wedge \exists x Lx]$

(6) $M, [], a, b\vec{e} \models$ (5) iff
$M, [], \langle\rangle, b\vec{e} \models S\mathtt{p}_1$ and $M, [], a, b\vec{e} \models \exists x Lx$ iff
$M, [], \langle\rangle, b\vec{e} \models S\mathtt{p}_1$ and $M, [x \mapsto a], \langle\rangle, b\vec{e} \models Lx$ iff
$b \in M(S)$ and $a \in M(L)$.

and by (7), where their values may come from the same witness, as illustrated in (8):

(7) Someone smiles and he laughs. $[\exists x Sx \wedge L\mathtt{p}_1]$

(8) $M, [], a, \vec{e} \models$ (7) iff
$M, [], a, \vec{e} \models \exists x Sx$ and $M, [], \langle\rangle, a\vec{e} \models L\mathtt{p}_1$ iff
$M, [x \mapsto a], \langle\rangle, \vec{e} \models Sx$ and $M, [], \langle\rangle, a\vec{e} \models L\mathtt{p}_1$ iff
$a \in M(S)$ and $a \in M(L)$.

Thus, $\mathtt{p}_i$ in taking as its denotation the *i*-th witness from the FS, receives an interpretation that is coreferential with the *i*-th existential quantifier occurrence found when going back in the discourse from the place where the pointer occurs.

3.6 The BAR

The novel ingredient of the system is the $[\mathtt{BAR}\backslash X]$ operator. This resets the assignment function by removing all assignments of values to variables not in X, and adds to the front of the FS all values so removed, see e.g. (9). In addition, (9) shows that, as a consequence of being added to the FS, values removed from the assignment remain out of the reach of subsequent quantifier actions, but enter into the reach of pointers. Thus, while the first occurrence of $\exists x$ no longer binds x of $Pxy\mathtt{p}_1$, it does bind (or rather is 'colinked' with) $\mathtt{p}_1$.

(9) $M,[y \mapsto c], ab, \vec{e} \models \exists x\,\mathtt{[BAR}\backslash y\mathtt{]}\,\exists x Pxy\mathtt{p}_1$ iff
$M,[x \mapsto a, y \mapsto c], b, \vec{e} \models \mathtt{[BAR}\backslash y\mathtt{]}\,\exists x Pxy\mathtt{p}_1$ iff
$M, \Downarrow([x \mapsto a, y \mapsto c], \{y\}), b, \Uparrow([x \mapsto a, y \mapsto c], \{y\}) + \vec{e} \models \exists x Pxy\mathtt{p}_1$ iff
$M,[y \mapsto c], b, a\vec{e} \models \exists x Pxy\mathtt{p}_1$ iff
$M,[x \mapsto b, y \mapsto c], \langle\rangle, a\vec{e} \models Pxy\mathtt{p}_1$ iff
$\langle b, c, a\rangle \in M(P)$.

Also note that $\mathtt{[BAR}\backslash y\mathtt{]}$ can only scope over formulas that, apart from leaving y free, are semantically saturated. All other formulas crash. $\mathtt{[BAR}\backslash\emptyset\mathtt{]}$, which will be abbreviated to plain $\mathtt{[BAR]}$ in what follows, needs a semantically saturated formula.

It is worth noting that $\mathtt{[BAR]}$'s behaviour is somewhat akin to a conjunct's, in the sense that all freshly introduced values shift to the FS. For example, the calculations of (10) and (11) are closely related: the one notable difference is the whereabouts in the starting NS of the value that the existential quantifier takes. (Note that, in the remaining examples of this section, n is the length $l(\phi)$ of ϕ.)

(10) $M, [], \langle dc_1...c_n\rangle, \langle e_1...\rangle \models \exists x\,\mathtt{[BAR]}\,\phi$ iff
$M, [x \mapsto d], \langle c_1...c_n\rangle, \langle e_1...\rangle \models \mathtt{[BAR]}\,\phi$ iff
$M, [], \langle c_1...c_n\rangle, \langle de_1...\rangle \models \phi$

(11) $M, [], \langle c_1...c_n d\rangle, \langle e_1...\rangle \models \exists x(x = x) \wedge \phi$ iff
$M, [], \langle d\rangle, \langle e_1...\rangle \models \exists x(x = x)$ and
$M, [], \langle c_1...c_n\rangle, \langle de_1...\rangle \models \phi$

However, the similarity breaks down when quantified contexts are involved. As (12) shows, such a context has the effect of making values introduced in the first conjunct unavailable to pronouns in the second conjunct. That is, values never make it to the FS.

(12) $M, [], \langle c_1...c_n\rangle, \langle e_1...\rangle \models \neg\exists x Px \wedge \phi$ iff
$M, [], \langle c_1...c_n\rangle, \langle e_1...\rangle \models \neg\exists x Px$ and
$M, [], \langle c_1...c_n\rangle, \langle e_1...\rangle \models \phi$

In contrast, as (13) shows, values introduced in quantified contexts are still passed onto the FS by a $\mathtt{[BAR]}$ occurrence. As a consequence, whenever a pronoun links up to a value that is sent to the FS by a $\mathtt{[BAR]}$, the effect is exactly one of being bound by the operator that introduced the value.

(13) $M, [], \langle\rangle, \langle e_1...\rangle \models \neg\exists x\,\mathtt{[BAR]}\,\phi$ iff
$\neg\exists\langle dc_1...c_n\rangle \in D^{n+1}(M, [], \langle dc_1...c_n\rangle, \langle e_1...\rangle \models \exists x\,\mathtt{[BAR]}\,\phi$ iff
$M, [x \mapsto d], \langle c_1...c_n\rangle, \langle e_1...\rangle \models \mathtt{[BAR]}\,\phi$ iff
$M, [], \langle c_1...c_n\rangle, \langle de_1...\rangle \models \phi\ )$

3.7 Summary

To sum up, we note that the interpretation procedure of *PLB* returns undefinedness:

- if a variable is not assigned a value at its point of evaluation (possible because the assignment function is partial);
- if a formula with either form $Pt,\ldots,t_n$ or $\neg\phi$ is evaluated with respect to a non-empty NS (ensures there are not too many witnesses);
- if an existential quantifier $\exists x\phi$ is evaluated with respect to an empty NS (ensures enough witnesses);
- if a pronoun $\mathtt{p}_i$ is evaluated with respect to a FS with length less than i (requires that the discourse context supplies a suitable range of antecedents).

Moreover we should note that the system gives rise to four types of binding relations:

(i) bound (in an operator-variable relation),

(ii) colinked (linked to the same witness) — equivalent of 'donkey anaphora', and so can have the effect of mimicking a binding relation (in all quantified contexts when induced by a `[BAR]`),

(iii) covalued (linked to different witnesses with the same denotation), and

(iv) disjoint in reference (linked to different witnesses with different denotations).

4 Locality effects

We now turn to see what *PLB* has to say about a number of locality effects in natural language. We first look at binding (condition A, B and C) effects. Then we look at constraints on movement (A-bar and A). We end with a look at strong crossover violations.

4.1 Some binding theory effects

In this section we consider what *PLB* has to say about the locality contrast between reflexives and non-reflexive pronouns. Given that `[BAR]`'s are introduced at the clausal level, reflexives are variables, and pronouns are interpreted as follows:

(14) $$M,g,\vec{c},\vec{e} \models HE_i(\lambda x\, \psi) \text{ iff } M,g,\vec{c},\vec{e} \models \exists x(x = \mathtt{p}_i \wedge \psi)\ ,$$

then the contrasts of (15) and (16), typically attributed to conditions A and B of Binding Theory (Chomsky, 1981), are expected.

(15) a. Someone$_1$ dislikes himself$_{1/*2}$
b. Someone$_1$ dislikes him$_{*1/2}$

(16) a. [A boy]$_2$ thinks [$_{\mathrm{CP}}$ that [a man]$_1$ dislikes himself$_{1/*2}$]
b. [A boy]$_2$ thinks [$_{\mathrm{CP}}$ that [a man]$_1$ dislikes him$_{*1/2}$]

In (15a), *someone* and *himself* have to be coreferential: the occurrence of [BAR] at the clausal level removes all value assignments, making x, bound by *someone*, the only variable assigned a value when *himself* is interpreted. (17) illustrates:

(17) $M, [x \mapsto a, y \mapsto c], b, \vec{e} \models \texttt{[BAR]}\exists x Dxx$ iff
$M, [], b, ac\vec{e} \models \exists x Dxx$ iff
$M, [x \mapsto b], \langle\rangle, ac\vec{e} \models Dxx.$

In (15b), *someone* and *him* cannot be coreferential: *someone* removes the witness it takes as its value from the witness sequence, placing it into the assignment function where it is unavailable for the non-reflexive pronoun. (18) illustrates:

(18) $M, [x \mapsto a, y \mapsto c], ba, \vec{e} \models \texttt{[BAR]}\exists x HE_1(\lambda y\, Dxy))$ iff
$M, [], ba, ac\vec{e} \models \exists x HE_1(\lambda y\, Dxy)$ iff
$M, [x \mapsto b], a, ac\vec{e} \models \exists y (y = \texttt{p}_1 \wedge Dxy)$ iff
$M, [x \mapsto b, y \mapsto a], \langle\rangle, ac\vec{e} \models Dxy.$

In (16a), *himself* cannot corefer with *a boy*, but rather must corefer with *a man*, which is the only active binding operator at the point of *himself*'s interpretation. (19) illustrates (abstracting away the contribution of the matrix [BAR] occurrence, *boy*, *man* and *thinks*):

(19) $M, [], ab, \vec{e} \models \exists x \texttt{[BAR]}\exists x Dxx$ iff
$M, [x \mapsto a], b, \vec{e} \models \texttt{[BAR]}\exists x Dxx$ iff
$M, [], b, a\vec{e} \models \exists x Dxx$ iff
$M, [x \mapsto b], \langle\rangle, a\vec{e} \models Dxx.$

In (16b), *him* cannot corefer with *a man*, but it can corefer with *a boy*. This is because the [BAR] moves *a boy*'s witness from the assignment function to the FS. This has the effect of making *a boy*'s witness unavailable for reflexives but available for pronouns. (20) illustrates:

(20) $M, [], aba, \vec{e} \models \exists x \texttt{[BAR]}\exists x HE_1(\lambda y\, Dxy)$ iff
$M, [x \mapsto a], ba, \vec{e} \models \texttt{[BAR]}\exists x HE_1(\lambda y\, Dxy)$ iff
$M, [], ba, a\vec{e} \models \exists x HE_1(\lambda y\, Dxy)$ iff
$M, [x \mapsto b], a, a\vec{e} \models \exists y (y = \texttt{p}_1 \wedge Dxy)$ iff
$M, [x \mapsto b, y \mapsto a], \langle\rangle, a\vec{e} \models Dxy.$

4.2 Possessives

We've seen how *PLB* can capture the complementary distribution of reflexives and non-reflexive pronouns. This raises the question of what to do with possessive pronouns, since, as (21) shows, they are not locally restricted.

(21) [A man]$_1$ admires his$_1$ father.

A solution that makes crucial use of the [BAR] is given in (22):

(22) $M, g, \vec{c}, \vec{e} \models HIS_i(P)(\lambda x\, \psi)$ iff $M, g, \vec{c}, \vec{e} \models \exists x (\texttt{[BAR}\backslash x\texttt{]}\, Px\texttt{p}_i \wedge \psi)$.

Thus, a possessive introduces a pointer, just like a non-reflexive pronoun, but has this placed immediately below a [BAR$\backslash x$], where x takes on the value the possessive is about. As a consequence all values introduced up to the point of the possessive's occurrence, with the exception of x's value, are made accessible to the possessive's pointer. (24) and (25) illustrate how this captures the ambiguity of (23), with the father the man's in (24) and the boy's in (25).

(23) [A boy]$_2$ thinks [$_{\mathrm{CP}}$ that [a man]$_1$ admires his$_{1/2}$ father].

(24) $M, [], abc, \vec{e} \models \exists x\,\mathtt{[BAR]}\,\exists x HIS_1(F)(\lambda y\, Axy)$ iff
$M, [y \mapsto c], \langle\rangle, ba\vec{e} \models Fy\mathtt{p}_1$ and $M, [x \mapsto b, y \mapsto c], \langle\rangle, a\vec{e} \models Axy$ iff
$\langle c, b\rangle \in M(F)$ and $\langle b, c\rangle \in M(A)$.

(25) $M, [], abc, \vec{e} \models \exists x\,\mathtt{[BAR]}\,\exists x HIS_2(F)(\lambda y\, Axy)$ iff
$M, [y \mapsto c], \langle\rangle, ba\vec{e} \models Fy\mathtt{p}_2$ and $M, [x \mapsto b, y \mapsto c], \langle\rangle, a\vec{e} \models Axy$ iff
$\langle c, a\rangle \in M(F)$ and $\langle b, c\rangle \in M(A)$.

4.3 Condition C effects

In (26), *he* and *someone* are not able to enter into a binding relation. As (27) shows, this is expected: the structure of (26) dictates that *he* must take its witness from the FS before *someone* has taken its referent from the NS. Witnesses only cross from the NS to the FS.

(26) He likes someone.

(27) $M, [], ba, b\vec{e} \models \mathtt{[BAR]}\,HE_1(\lambda x\, \exists y Qxy)$ iff
$M, [], ba, b\vec{e} \models \exists x(x = \mathtt{p}_1 \wedge \exists y Qxy)$ iff
$M, [x \mapsto b], a, b\vec{e} \models \exists y Qxy$ iff
$M, [x \mapsto b, y \mapsto a], \langle\rangle, b\vec{e} \models Qxy$.

Moreover, if *someone* scopes over the pronoun (e.g. as it would if it were quantifier raised), the impossibility of coreferential dependence is maintained, as (28) illustrates (cf. the discussion of the strong crossover effect in section 4.6):

(28) $M, [], ab, b\vec{e} \models \exists y HE_1(\lambda x\, Qxy)$ iff
$M, [y \mapsto a], b, b\vec{e} \models \exists x(x = \mathtt{p}_1 \wedge Qxy)$ iff
$M, [x \mapsto b, y \mapsto a], \langle\rangle, b\vec{e} \models Qxy$.

4.4 A-bar-movement

Since Chomsky (1973) it has come to be widely thought that apparently unbound connections, such as between *who* and *e* of (29), are in fact mediated by sequences of relatively local movements targeting successively higher (usually SpecCP) positions: in (29), from *e* to *who*'s ultimate position, giving the schematised derivation of (30).

(29) Mary met an artist <u>who</u> she thought John had said she should commission <u>e</u>.

(30) $(Op\, x)$ [$_{\mathrm{CP}}$ t$_x$ C [$_{\mathrm{TP}}$ ... [$_{\mathrm{CP}}$ t$_x$ C [$_{\mathrm{TP}}$ ... [$_{\mathrm{CP}}$ t$_x$ C [$_{\mathrm{TP}}$ ... x ...]]]]]]

This general line of analysis has gained wide-spread acceptance, largely because of the theory of island-hood that it supports. Also, languages have been found to provide morphosyntactic confirmation for the core idea that seemingly long movements are compositions of more local operations (e.g., McCloskey (1979) observes that Irish leaves detectable signs that the postulated intermediate movements have applied). For us, (30) gives a potential indication as to what saves

(29), namely, the existence of intermediate traces "t_x" that are local enough to the variable/empty slot. But how to make sense of what intermediate traces are?

Let's assume that material moved in a syntactic derivation is always basically variable information (other material counts as pied-piped). Moreover, let's assume that "strong phase boundaries" (Chomsky, 2001) (e.g. CP) are occurrences of $\texttt{[BAR}\backslash X\texttt{]}$ (we have been assuming this since section 4.1, where it was instrumental in capturing the binding effects) and that the syntactic operation of leaving a trace in SpecCP exists to provide information to the X. That is, movement of variable information x to SpecCP has the effect of coindexing the `[BAR]` introduced by the CP thus $\texttt{[BAR}\backslash x\texttt{]}$. It is this that makes the movement count as an A-bar movement, and it is this that has the effect of maintaining x as a variable that continues to receive an interpretation past the $\texttt{[BAR}\backslash x\texttt{]}$ occurrence. Consequently such a movement can be seen to cross a CP boundary. For example, the relative clause "who she thought ..." of (29) takes on the form of (31):

(31) $$\texttt{[BAR}\backslash y\texttt{]}\, SHE_1(\lambda x\, thought(x, \texttt{[BAR}\backslash y\texttt{]}\ john\text{-}said(\texttt{[BAR}\backslash y\texttt{]}\, SHE_2(\lambda x\, commission(x,y)))))$$

Thus, each `[BAR]` occurrence in (31) gives rise to the need for a movement that has the effect of preventing y from having to be semantically closed. That is, movement can be used to maintain an open proposition, but only when it is successive cyclic.

It should be noted that so far nothing has been said about why natural language should have to resort to using `[BAR]`'s. But suppose the semantic system of natural language has to juggle a parsimonious inventory of variables, $w, x, y, z, \ldots$ (see e.g. Hurford, 2001). Yet it is rich and powerful enough to allow for the construction of arbitrarily complex properties. A way to maintain such expressiveness is to rebind. The `[BAR]` can be seen as a means for managing rebinding, making locality requirements a reflex of this strategy.

4.5 A-movement

In addition to A-bar-movements that target a position in the CP domain (like wh-movement to SpecCP), languages can have other syntactic displacement operations that target clause-internal (TP-internal) positions. These include: NP-movement, scrambling and extraposition (see e.g. Williams (1994) on NP-movement, Fanselow (2001) on scrambling, Culicover and Rochemont (1990) on extraposition, among others). A common property of these movement types is that they are clause-bound. That is, they cannot cross a CP and target a TP-internal position in a higher clause. This is illustrated in (32):

(32) $*\ldots [_{TP} \ldots \alpha_1 \ldots [_{CP} \ldots [_{TP} \ldots t_1 \ldots] \ldots$

That (32) holds is accounted for by the locality constraint that permits extraction from a CP only via SpecCP.

4.6 Strong crossover

The strong crossover phenomenon, first noted in Postal (1971), designates binding failures like those in (33) (taken from Postal, 1997):

(33) a. *[$_{\text{CP}}$ Who$_1$ did Frank convince her$_1$ [$_{\text{CP}}$ t$_1$ that you would hire e$_1$]]?
b. *the principle$_1$ [$_{\text{CP}}$ which$_1$ I inferred from it$_1$ [$_{\text{CP}}$ t$_1$ that no other principle entailed e$_1$]]
c. *[$_{\text{CP}}$ What$_1$ Jane compared it$_1$ to a model of e$_1$] was the Eiffel Tower.
d. *It doesn't matter [$_{\text{CP}}$ who$_1$ they claim she$_1$ believes you should invite e$_1$].

Such failures come as a direct consequence of non-reflexive pronouns only being able to take values from the FS (which was also the reason given for condition C effects in section 4.3). Moreover, since successive cyclic movement is required (section 4.4), strong crossover effects are enforced all the way up the syntactic tree (to the point where the movement stops). Alternatively put, as a consequence of extending the domain in which variables can be bound (and so used), movement via a `[BAR]` has the reverse effect of excluding pronouns. Example (34) illustrates an existential "moving through" two `[BAR]` occurrences. As a consequence, the value it gets assigned (namely: *a*) is kept in the assignment function throughout the semantic calculation, and so out of reach for the pronoun's pointer.

(34)
$$\begin{array}{l} M,[],ab,b\vec{e} \models \exists x\,\texttt{[BAR}\backslash x\texttt{]}\,HE_1(\lambda y\,\texttt{[BAR}\backslash x\texttt{]}\,Qx) \text{ iff} \\ M,[x\mapsto a],b,b\vec{e} \models \texttt{[BAR}\backslash x\texttt{]}\,HE_1(\lambda y\,\texttt{[BAR}\backslash x\texttt{]}\,Qx) \text{ iff} \\ M,[x\mapsto a],b,b\vec{e} \models \exists y(y=\texttt{p}_1 \wedge \texttt{[BAR}\backslash x\texttt{]}\,Qx) \text{ iff} \\ M,[x\mapsto a,y\mapsto b],\langle\rangle,b\vec{e} \models \texttt{[BAR}\backslash x\texttt{]}\,Qx \text{ iff} \\ M,[x\mapsto a],\langle\rangle,bb\vec{e} \models Qx \end{array}$$

For the same reason, coreference of the topicalised (another wh-movement like operation, see e.g. van Riemsdijk and Williams, 1986) *someone* and *he* in (35) gets ruled out, as (36) illustrates.

(35) Someone, he likes e.

(36)
$$\begin{array}{l} M,[],ab,b\vec{e} \models \exists y\,\texttt{[BAR}\backslash y\texttt{]}\,HE_1(\lambda x Pxy) \text{ iff} \\ M,[y\mapsto a],b,b\vec{e} \models \texttt{[BAR}\backslash y\texttt{]}\,HE_1(\lambda x Pxy) \text{ iff} \\ M,[y\mapsto a],b,b\vec{e} \models \exists x(x=\texttt{p}_1 \wedge Pxy) \text{ iff} \\ M,[x\mapsto b,y\mapsto a],\langle\rangle,b\vec{e} \models Pxy \text{ iff} \\ \langle a,b\rangle \in E(P) \end{array}$$

5 Conclusion

In this paper we introduced the system of Predicate Logic with Barriers. This was shown to have various interesting properties that arose out of the barrier operator's presence. In particular, it was shown to reproduce a number of locality effects found in natural language: condition A, B and C effects, locality constraints on different types of movement (A-bar and A), and strong crossover violations.

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