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Reciprocal Interpretation with Functional Pronouns

Alexis Dimitriadis
University of Pennsylvania

Sentence (1) has a reading under which John thinks "I like Mary," and Mary thinks "I like John." Under this reading, the "dependent" pronoun *they* is most naturally represented as a bound variable, and is therefore semantically singular.[1] But this pronoun is also the antecedent of the reciprocal *each other;* it is well-known that reciprocals require a plural antecedent, so where does this one find the plural antecedent it requires?

(1) John and Mary think they like each other.

The standard way to account for the dependent reading (Heim et al. 1991a, and many others) is to have the reciprocal find its plural antecedent (its *range* argument) outside the embedded clause, by raising via QR or simply by being bound non-locally. Heim et al. (1991a) give sentence (1) the following analysis:

(2) [John and Mary$_1$ each$_2$] think [that they$_2$ like [e$_2$ other]$_3$]
= John thinks "I like Mary", and Mary thinks "I like John".

In this representation, the *each* part of the reciprocal has raised to adjoin to the matrix subject, where it functions as a distributive operator introducing universal quantification over the atomic parts of the matrix subject, the plural individual *John and Mary;* it also binds the pronoun *they*$_2$ and its own movement trace e_2. The representation in (2) translates into the following semantics:

(3) $(\forall x_2 \cdot\Pi\, \mathrm{J}{\oplus}\mathrm{M}_1)\, \mathrm{think}(x_2, {}^\wedge[(\forall x_3 \cdot\Pi\, X_1)\ x_2 \neq x_3 \Rightarrow \mathrm{like}(x_2, x_3)])$

Here the lower universal quantifier is contributed by the remnant part of the reciprocal (e_2 *other*), which is assumed to raise locally. (The symbol $\cdot\Pi$ stands for *proper-atomic-part-of).*

This solution works because the dependent pronoun ranges over the elements of the matrix subject. Indeed, since reciprocals are subject to Binding Principle A, it is necessary to stipulate that such "long-distance" reciprocals are only possible when the embedded subject is bound by the distributor of the matrix subject. For example, sentence (4) does not have a long-distance interpretation (or any other, since the embedded subject is singular).

(4) * Ann and Mary think that I like each other.

However, there are configurations that allow dependent reciprocal readings under conditions of non-identity between the matrix and embedded subjects. Heim et al. were aware of sentences like (5a), and accounted for them by assuming that the possessive pronoun raises out of the subject NP, to a position from where it can bind the embedded subject. But examples like (5b) and (c) have dependent readings that are just as good, and they are not so easily accounted for. In (b),

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[1] I will refer to this reading, non-standardly, as the *dependent* reading, as opposed to the *independent* reading which says that John and Mary both think the same proposition, "We like each other." Heim, Lasnik, and May (1991a), among others, have shown that the dependent plural reading of reciprocal sentences is distinct from a cumulative (i.e., vague) construal. If the embedded pronoun was interpreted cumulatively, it should be equally easy, given the right context, to derive the following "crossed" reading of sentence (1):

(i) John thinks that Mary likes him, and Mary thinks that John likes her.

But this reading is unavailable, or at least much harder to get than the dependent reading. It can also be shown that sentences with dependent pronouns have truth conditions that are stronger than those of corresponding sentences with full NPs.

the pronoun *them* would have to raise out of a relative clause; in (c), a reciprocal that long-distance raises would give the reading "John thinks that his mother likes Mary, and Mary thinks that her mother likes John." This reading is impossible; the correct reading, in which John thinks that his mother likes Mary's *mother* and vice versa, cannot be generated by raising the reciprocal.[2]

(5) a. Their coaches think they will defeat each other.
    b. The lawyers that represent them_i say they_i will sue each other.
    c. John and Mary think their mothers like each other.

The problem with such examples is that the binder of the reciprocal determines the reciprocal's *range argument,* the set of entities that the object of the reciprocal clause may range over: The dependent reading of sentence (5c) is that John thinks his mother likes Mary's mother, but wide scope for the reciprocal would say that John's mother saw Mary, and vice versa (or worse, that *John* saw Mary). Such interpretations are never possible: reciprocals always range over the same elements their local antecedent ranges over, regardless of what *that* may be dependent on.

What is needed for these examples is some way for the object of the reciprocal predicate to range over the elements of the embedded, not the matrix, subject; in sentence (5c), that would be the set of mothers. But if the "long-distance" reading involves the translation of the embedded subject as a bound variable, there is no potential antecedent anywhere in (c) that translates to the set of mothers!

The account I propose has two parts: first, we need a way for the dependent pronoun in (5b) to be effectively bound by an NP that is inside a relative clause. This is accomplished by treating the pronoun *they* as a paycheck pronoun, in the fashion of Engdahl's (1986) functional adaptation of Cooper (1979). Accordingly, dependent pronouns are translated as expressions of the form $W(u)$, where W is a free variable of type <e, e> and u is a free variable over individuals. The pronoun in (5b) is then interpreted as a function meaning something like "their clients", and sentence (5b) can be treated in whatever way we handle sentence (5c).

Second, we need a way to generate the set of values that the "range argument" of the reciprocal should range over. I propose that the reciprocal predicate uses the function represented by the embedded subject to generate this set. The problem is that under the standard treatments of paycheck pronouns, including Engdahl's, the embedded subject is not a function but a complex expression of type <e>, consisting of the function plus its argument (a variable bound by the matrix distributor). The desired function could only be recovered from this subject via lambda abstraction; if the subject is instead passed to some other expression (e.g., to the reciprocal predicate) via Functional Application, there is no way for the subject to be converted back into a function.

In earlier work (Dimitriadis, forthcoming), I treated the function argument needed by the reciprocal as a free variable, constrained by binding theory to match the function in the embedded subject (more generally: in the local ancecedent of the reciprocal). But in the framework of Jacobson's (1999a, 1999b) Variable Free Semantics, all pronouns are represented as functions (of type <e,e>), not as variables over individuals. This means that the function corresponding to the embedded pronoun is accessible to the reciprocal predicate, and there are a number of ways to recover the range of the reciprocal from such a function. One possibility is to generate the range by applying the function to the matrix subject; for example, in (5b) the set of lawyers is mapped to the set of clients. Another is to posit, as

[2]Heim et al. do not actually predict that the erroneous reading is possible: it is ruled out by their requirement that the reciprocal be coindexed with a local A-binder. But this means that there is no way to derive the correct reading of (5c), either. If the A-binder requirement was somehow relaxed to allow for long-distance reciprocals in this case, the best their system could do is predict the non-existent reading, as discussed.

in (Dimitriadis, forthcoming), that reference functions are implicitly resricted; the range can then be recovered by means of a maximality operator.

1 The range of reciprocals

A correct translation of sentence (5b) should claim that each lawyer x says that x's client will sue the other clients, or the other lawyers' clients. Even with the paycheck analysis of the dependent pronoun, the framework of Heim et al. (1991a) cannot generate this reading. If, contrary to the restrictions in their system, we were to allow a long-distance reciprocal in this sentence, it might receive the following interpretation:

(6) $(\forall x_2 \cdot \Pi\, \mathbf{lawyers}_1)\, \mathrm{say}(x_2, \hat{}[(\forall x_3 \cdot \Pi\, X_1)\ W(x_2) \neq x_3 \Rightarrow \mathrm{sue}(W(x_2), x_3)])$

This says that each lawyer expects his/her client to sue the other *lawyers.* The correct translation can be generated if we stipulate that the range argument of the reciprocal, the free variable X, should be interpreted as the set of clients instead of being coindexed with $\mathbf{lawyers}_1$; but this implies that the range of the reciprocal could be any set, when in fact it is rigidly determined: it can only be the set of entities that the reciprocal's *contrast argument,* $W(x_2)$, ranges over.

This problem is not limited to the account of Heim et al.; its equivalent is also found in other scopal treatments of reciprocals, including those of Sternefeld (1998) and Schwarzschild (1996). Sternefeld, for example, captures the semantics of weak reciprocity via membership in the cumulation of the reciprocal predicate. (In contrast, the account of Heim et al. relies on direct quantification and encodes the semantics of strong reciprocity). In dependent reciprocal sentences the entire reciprocal raises to the matrix clause, so that the dependent reading of (5b) would be as follows:

(7) $(\exists X)(X = \mathbf{lawyers} \wedge \langle X, X\rangle \in {}^{**}\lambda xy[x \neq y \wedge \mathrm{say}(x, \hat{}[\mathrm{sue}(W(x), y)])])$

This is the same meaning as given by the Heim et al. (1991a) analysis: it claims that each lawyer x said that his or her client, $W(x)$, will sue one or more of the other *lawyers,* y. The correct semantics would require replacing the the last occurrence of y with $W(y)$.

Thus the problem of finding the right range for the reciprocal is not specific to the analysis of Heim et al. (1991a), or to their particular assumptions about distributivity or type of reciprocal relation. The core of the issue seems to be that the range of the dependent reciprocal depends on its local antecedent, but the raising analysis cannot properly take its contribution into account.

The question, then, is how to translate long-distance reciprocals so that the reference function of the reciprocal predicate's subject plays a role in computing the range argument of the reciprocal. To do that it is necessary for the reciprocal to have direct access to the function represented by the dependent pronoun, something that can be done in a natural way in the framework of Jacobson's (1999a, 1999b) Variable Free Semantics.

2 Variable-free semantics

Jacobson's system translates pronouns as the identity function $\lambda x.x$, an expression of type $< e, e >$). To allow them to occur in the same syntactic positions as ordinary NPs, she introduces families of type-shifting operators g and z, which allow unsaturated functions to combine properly with other sentence elements. The operator g achieves the equivalent of function composition: an expression expecting an NP can be combined with a function from individuals to NPs instead, and the result is a function from individuals to the original type of the expression, b. The operator z, applied to a transitive expression like *love,* replaces one of its arguments with a function bound by a higher argument.

Space does not permit a proper exposition of Jacobson's system, so simplified versions of g and z are included here without comment:

(8) a. $g_c(\lambda a.t(a)) = \lambda f \lambda c.[t(f(c))]$ (<a, b> → <ca, cb>)
b. $z_b(\lambda x \lambda y.p(x)(y)) = \lambda f \lambda y.p(f(y))(y)$ (<X, eY> → <eX, eY>)

With the aid of z, the functions corresponding to bound pronouns are eventually supplied with the correct antecedent as their argument. Discourse pronouns remain unbound; the sentences they occur in translate into functions from individuals to sentences. For example, sentence (9a) is translated as in (b).

(9) a. Mary loves him.
b. $\lambda x.\text{loves}(f(x))(\mathbf{m})$

The context then supplies a salient individual as the referent of *him.*

An added benefit of the variable-free approach is that lexical NPs containing a dependent pronoun are compositionally translated as functions, and can therefore be handled just like simple pronouns. (Recall that sentences like (5c), in which the dependent pronoun was embedded in an NP, cannot be handled by the standard treatment). The NP *their mothers* in (5c) is translated compositionally into the function $\lambda x.{}^*\text{mother-of}(x)$.

2.1 Paycheck pronouns

While ordinary pronouns are treated as the identity map on individuals, $\lambda x_e.x$, Jacobson translates paycheck pronouns as the identity map on functions of type <e,e>, $\lambda f.f$ (or $\lambda f \lambda x.f(x)$). This is simply the result of applying the g operator to the identity function on individuals, so all pronouns can be given the same underlying representation. The second sentence of (10) is is translated as $\lambda f.\text{hates}(f(b))(b)$. In this case, the context supplies the mother function as the argument f.

(10) John loves his mother. Bill hates *her.*

3 Reciprocals in the variable-free system

For concreteness, I will use as a starting point the treatment suggested in (Heim, Lasnik, and May, 1991b), in which the *each* part of the reciprocal does not raise; its role is taken over by a covert distributor that is freely inserted, as in simple distributive sentences. We can then replace their their distributor (an NP operator) with a VP-adjoined one, that provides the same universal quantification over individual elements of the subject:

(11) $D = \lambda P \lambda z.(\forall x \cdot \Pi\, z)P(x)$

The translation that Heim et al. give to the reciprocal can be written as in (12a). The quantifier ranges over the possible objects of the reciprocal predicate. (A higher universal quantifier is introduced by the distributor). For the variable-free version we rewrite the range argument, the free variable X_i, as an extra argument of the reciprocal. After some more adjustments to allow evaluation over non-atomic individuals, we obtain the version given in (12b):[3]

(12) a. $\lambda \zeta \lambda y.\forall x_k(x_k \cdot \Pi\, X_i \,\&\, x_k \neq y)\zeta'(y, x_k)$
b. $\lambda P \lambda R \lambda x.(\forall y \cdot \Pi\, R, y \wedge x = \mathbf{0})P(y)(x)$

[3]The symbol "$\wedge$" is the meet operation on the semilattice of individuals, i.e., x and y must have no part in common.

The range argument in effect causes the reciprocal to be treated as if it contained a pronoun; at any stage it can be bound via the z operator, or remain unbound and be passed up with the help of g.

In an ordinary distributed sentence, the distributor is directly combined with the VP, and can then be applied to the subject:

(13) a. (John and Mary) + D(ran).
$[\lambda z.(\forall x \cdot\Pi\, z)\text{ran}(x)](\text{John and Mary})$

Because of the extra argument of a reciprocal predicate, it cannot combine directly with D; it combines with $z(D)$ instead, to give (14b):

(14) a. $z(D) = \lambda Q\lambda z.\forall x \leq z\; Q(z)(x)$
b. $z(D)$ + (like each other) $= \lambda z.\,(\forall x \leq z)\;(\forall y \cdot\Pi\, z,\; y{\wedge}x = \mathbf{0})\;\text{like}(y)(x)$

This is simply the Heim et al. account translated into variable-free semantics, but with VP-adjoined distributors. Because the subject is not buried in the subject-distributor complex as as it would be if the distributor was NP-adjoined, the range argument can be recovered from the distributor, as shown, instead of being left as a free variable. But this account is as incapable of handling dependent paycheck pronouns as the original; if the reciprocal predicate (14b) is not combined with a distributor, but is instead combined with a dependent paycheck pronoun, we get:

(15) a. The lawyers who represent John and Mary say they like each other.
b. they $= \lambda f\lambda w.f(w))$
c. like each other $= \lambda R\lambda x.(\forall y \cdot\Pi\, R, y{\wedge}x = \mathbf{0})\;\text{like}(y)(x)$
d. g(l(they)) + g(like each other) =
$\lambda R\lambda f\lambda w.(\forall y \cdot\Pi\, R, y{\wedge}f(w) = \mathbf{0})\;\text{like}(y)(f(w))$

(The pronoun type-lifts to $\lambda P\lambda f\lambda w.P(f(w))$, via l, then undergoes g in order to pass up the argument λR of the predicate). It can be seen that the paycheck function f is only applied to the subject of the reciprocal predicate; when the entire sentence is translated, the range argument R will be identified with the denotation of the matrix subject, which gives us the non-existent reading of clients liking lawyers.

3.1 Using the domain

What kind of adjustments can be made to give the correct semantics? If the translation of the reciprocal can expect to be combined with a functional subject, then we can dispense with the range argument and use the domain or range of the antecedent function in its place, translating the reciprocal as in (16a) or (b):

(16) a. $\lambda P\lambda r\lambda x.(\forall y \cdot\Pi\,\text{Dom}(r), r(y){\wedge}r(x) = \mathbf{0})\;\text{P}(r(y))(r(x))$
b. $\lambda P\lambda r\lambda x.(\forall y \cdot\Pi\,\text{Range}(r), y{\wedge}r(x) = \mathbf{0})\;\text{P}(y)(r(x))$

For this to work, it is of course necessary that the pronoun functions come with domains, and that their domain be no larger than required by the pronoun's binder, i.e., the domain of a dependent pronoun should be co-extensive with the matrix subject. To keep things simple, I will write the domain as an open variable in the translation of the pronoun as in (17); it should actually be treated, in the variable-free spirit, as a second argument to the pronoun function. The domain of and range of a restricted function r are retrieved by application of the maximality operator; e.g., the domain is $\sigma x(\exists y\; r(x) = y)$. The restricted client function is:

(17) $r = \lambda x.\iota z(x \leq A\;\&\;\text{client-of}(z)(x))$

Given either of the translations in (16), we can capture the correct semantics for dependent reciprocals with or without paycheck pronouns.

The problem with the analysis as given is that it expects to find a function immediately above the reciprocal predicate. Although it is possible to arrange for the distributor to pass the identity function to the reciprocal, this step seems unmotivated and artificial. Given the translation we are after, there seems to be no way around this: if we start with an expression that expects a subject of type <e> and then type-shift to bind the pronoun, we end up with plain bound-pronoun semantics, and there is no way to compute the correct range argument. If we assume a function argument, we need to go through the unnatural step of introducing a reference function between a simple reciprocal predicate and its distributive antecedent.

3.2 Mapping the range argument

A second, perhaps less ad hoc solution is as follows: Start with the reciprocal translation given in (12b), combine it with a verb, then apply the g operator twice to change both arguments into functional expressions, as in (18a). If we can manage to use the antecedent's reference function r for *both* f and g, we get the correct semantics shown in (b).[4] For example, in the translation of sentence (5c) the variable y will range over mothers, not over the set R, which will consist of John and Mary.

(18) a. like each other:
$\lambda g \lambda R\, \lambda f \lambda x.\, (\forall y \cdot \Pi\, g(R), y \wedge f(x) = \mathbf{0}) like(y)(f(x))$
b. they + like each other:
$\lambda R \lambda x.\, (\forall y \cdot \Pi\, r(R), y \wedge r(x) = \mathbf{0}) like(y)(r(x))$

Jacobson's framework does not seem to provide an operation that can do this, but this seems like a good place to introduce an extension. Note that this solution does *not* rely on function domains, and (leaving aside the magic step from (18a) to (b)) uses a single translation for the reciprocal.

Conclusion

Jacobson's Variable-Free Semantics makes it possible to handle, in a constrained way, dependent reciprocal sentences in which the embedded subject ranges over different values than its binder. Although I based my discussion on the Heim et al. model, the proposed solution is applicable to other, more articulated treatments of reciprocals.

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[4] If the local antecedent is a paycheck pronoun, then r is actually a variable over functions, and expression (18b) should be amended to pass up the argument λr. If r is the identity function or an NP containing the dependent pronoun, (18b) is correct as written.