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Reciprocity: Anaphora, scope, and quantification*

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Abstract We present a relational analysis of reciprocity in the setting of Partial Plural Compositional Discourse Representation Theory (abbreviated as PPCDRT), combining ideas from Plural Compositional DRT and Partial Compositional DRT. Our analysis accounts for a wide range of data that are problematic for proposals involving quantification over individuals and for relational analyses relying on cumulative operators on predicates. We also provide an account of apparent "scope" ambiguities and long-distance readings which have been a focus of attention for quantificational analyses, but have not been adequately addressed by previous relational analyses. Our Partial Plural CDRT analysis also enables us to address other issues in the semantics of reciprocity. First, we provide a simple account of reciprocals with quantificational antecedents, whose analysis has been problematic for previous accounts. Second, it has often been noted that the meaning contribution of the reciprocal varies in strength, with some examples requiring the reciprocal relation to hold between every member of the relevant group, while others allow for a weaker relation. We explore an approach to this problem in our Partial Plural CDRT setting.

Keywords: reciprocity, anaphora, scope, quantification

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1 Overview

Langendoen (1978) was among the first to draw a connection between cumulativity and reciprocal meaning: he compared reciprocal sentences to what he called *elementary plural relational sentences* such as *The women released the prisoners*, where each woman released at least one prisoner and each prisoner was released by one of the women. Similarly, the reciprocal sentence *The women pointed at each other* requires each woman to point at another woman, and to be pointed at by another woman. Building on this insight, subsequent *relational* analyses have proposed that the reciprocal has two crucial components that link it to its antecedent. First, like a plural pronoun, it imposes a coreference requirement which is interpreted cumulatively: in the example *The women pointed at each other*, each woman is required to participate as both the agent and the patient of the pointing action. Second, it imposes a distinctness criterion which is interpreted distributively, requiring each woman to point at a different woman in each subcase. Analyses developing this view have been proposed by Sternefeld (1998) and Beck (2001) and, within dynamic semantics, Murray (2008) and Dotlačil (2013).

Relational analyses of reciprocity contrast with *quantificational* analyses involving distributive quantification over individuals, either explicitly, via a quantifier such as *each* (e.g., Heim, Lasnik & May 1991), or implicitly, via polyadic quantification over members of a group (e.g., Dalrymple et al. 1998).

(1) Two girls saw each other.

a. Distribution, following Heim, Lasnik & May (1991):
$\forall x \in \textsc{girls}.\forall y \in \textsc{girls}.y \neq x \rightarrow \textsc{see}(x, y)$

b. Polyadic quantification, following Dalrymple et al. (1998):
$\textsc{recip}(\textsc{girls}, \lambda x, y.\textsc{see}(x, y))$

As shown by Dotlačil (2013) among others, quantificational analyses of reciprocity face difficulties with a range of data for which relational analyses provide a straightforward treatment, including reciprocal/reflexive underspecification and cumulative readings, as well as readings where either the reciprocal or its antecedent is interpreted as a group, which are problematic on some relational analyses as well.

Nevertheless, there is one phenomenon which seems to provide strong support for quantificational analyses: scope ambiguity, as in (2).

(2) Two girls thought that they saw each other.

a. Narrow scope: Each thought: “We saw each other.”

b. Wide scope: Each thought: “I saw her”.

Quantificational analyses account for this ambiguity straightforwardly; we illustrate by reference to the analysis of Dalrymple et al. (1998):

(3) a. Narrow scope: $\textsc{think}(\textsc{girls}, \textsc{recip}(\textsc{girls}, \lambda x, y.\textsc{see}(x, y))$

b. Wide scope: $\textsc{recip}(\textsc{girls}, \lambda x, y.\textsc{think}(x, \textsc{see}(x, y)))$

The only relational analysis that addresses data like (2) is that of Sternefeld (1998), but that analysis has other problems, as we will see. The goal of this paper is therefore to extend the relational analysis to cover apparent scope effects, yielding the most encompassing analysis of reciprocals so far.

In the dynamic semantics setting of our analysis, like that of Murray (2008) and Dotlačil (2013), the reciprocal and its antecedent introduce two discourse referents linked by a special coreference condition which requires them to range over the same group but be distinct in each subcase. To extend this analysis to scope effects, we follow Williams's (1991) attractive proposal that the ambiguity we see in (3) is the same as the one we see in (4).

(4) Two girls thought that they would win.

a. Each girl thought: “We will win.” (“narrow scope”/group identity)

b. Each girl thought: “I will win.” (“wide scope”/bound anaphora)

Williams does not, however, formulate a semantic analysis of the ambiguity in (4), and it is in fact difficult to do so on the common assumption that the anaphoric relation between *two girls* and *they* is captured by coindexation/variable reuse, because that leaves no obvious way to parametrize the two readings. For that reason, we update our dynamic semantics with Haug's (2014) treatment of anaphora, where the two NPs introduce *different* discourse referents even if they corefer. Those discourse referents are linked by a coreference condition which, like other conditions, can be satisfied either at the individual level or at the group level. In Section 3 we show how this directly yields the ambiguity in examples such as (2) and (4). In Section 4, we show how the resulting theory combines the empirical coverage of both relational and quantificational theories. In Section 5, we extend the empirical coverage of our theory with a simple treatment of reciprocals with quantified antecedents, which have been problematic for all analyses so far.

Finally, in Section 6, we explore a new approach to accounting for the range of meanings which reciprocal sentences exhibit.

2 The relational analysis: Reciprocals through cumulation

We begin this section with an overview of the basic formal setting for our analysis, Plural Compositional DRT. We then introduce Partial CDRT, and update our treatment of anaphora to Partial Plural CDRT (PPCDRT). We discuss our reanalysis of some recalcitrant data involving plural anaphora and its interactions with distributivity, and present our treatment of plural anaphora in a PPCDRT setting. Finally, we present our PPCDRT analysis of reciprocity.

2.1 Plural Compositional DRT

Discourse Representation Theory (DRT: Kamp & Reyle 1993) is a theory of the interpretation of sentence sequences which is dynamic, providing an account of the introduction of discourse referents and subsequent reference to them via anaphoric expressions. Compositional DRT (Muskens 1996) makes DRT compositional by introducing types for discourse referents (often called registers) and information states, thereby handling assignments in the object language rather than in the metalanguage. Plural CDRT (Brasoveanu 2007) adapts van den Berg's (1996) plural dynamic logic to the compositional DRT setting.

In this setting, DRSs are not relations between information states, but relations between *sets* of information states: that is, plural information states. To define the introduction of a new discourse referent u in a plural information state, we need the notion of two singular information states differing at most with respect to u (5).[1]

1 We use the following notational conventions:

x, y, z	first-order variables
$P, P', R, \mathscr{Q}$	higher-order variables
$u, u_1, u_2 \ldots$	discourse referents
$s, i, o, o_1, o_2 \ldots$	information states
S, I, O	sets of information states/plural information states
d	individual
D	plural individual
K	Discourse Representation Structure

(5) $i[u_1]o$ in Compositional DRT (Muskens 1996):

$$i[u_1]o =_{def} \forall u.u \neq u_1 \rightarrow \nu(i)(u) = \nu(o)(u)$$

We extend this to plural information states following Brasoveanu (2007) and Dotlačil (2013): when a new discourse referent u is introduced, for each input assignment i there is an output assignment o that differs at most with respect to u; and for each output assignment o there is an input assignment i that differs at most with respect to u. Moreover, because we are quantifying over assignments, we must exclude the degenerate case where the set of output assignments is empty, so we include a condition $O \neq \emptyset$. This gives the definition in (6).

(6) $I[u]O$ in Plural CDRT (Dotlačil 2013: example (43), see also Brasoveanu 2007: p. 142):

$$I[u]O =_{def} \forall i \in I.\exists o \in O.i[u]o \wedge \forall o \in O.\exists i \in I.i[u]o \wedge O \neq \emptyset$$

We also require a notion of a plural information state satisfying a condition. Plural CDRT takes pointwise satisfaction of conditions as the default, i.e., for a plural information state S to satisfy a condition $R(u)$, every assignment s in S must provide a value for u such that $R(\nu(s)(u))$ holds. The condition $R(u)$ therefore abbreviates the expression in (7).

(7) Distributive satisfaction of conditions in Plural CDRT (Dotlačil 2013: example (39b), see also Brasoveanu 2007: p. 136):

$$R(u) =_{abbr} \lambda S.S \neq \emptyset \wedge \forall s \in S.R(\nu(s)(u))$$

Given this, a sentence containing a plural noun phrase is analyzed as in (8).

(8) a. Cats appeared.

b. $$\begin{array}{|l|}\hline u_1 \\ \hline cat(u_1) \\ appear(u_1) \\ \hline\end{array}$$

c. $\lambda I.\lambda O.I[u_1]O \wedge \forall o \in O.cat(\nu(o)(u_1)) \wedge appear(\nu(o)(u_1))$

(8a) is assigned the DRS-like interpretation (8b), which abbreviates the type theoretical expression (8c). A plural information state O satisfies (8c) in case it extends an input assignment I with values for u_1 such that each individual in u_1 is a cat who appeared.

We follow the standard 'inclusive' view of plurality, where plural form is compatible with singular reference, so there is no plurality constraint in (8). But how can we impose a plurality constraint e.g., for *two cats appeared*? We do this by summing across assignments, as defined in (9).

(9) Collective satisfaction of conditions in Plural CDRT (Dotlačil 2013: example (39a)):

$$R(\cup u) =_{abbr} \lambda S.S \neq \varnothing \wedge R(\bigcup_{s \in S} \nu(s)(u))$$

With this in place, we get (10).

(10) a. Two cats appeared.

b.
$$\begin{array}{|l|}\hline u_1 \\ \hline \\ cat(u_1) \\ 2\text{-}atoms(\cup u_1) \\ appear(u_1) \\ \\ \hline \end{array}$$

c. $\lambda I.\lambda O.I[u_1]O \wedge \forall o \in O.cat(\nu(o)(u_1))$
$\wedge 2\text{-}atoms(\bigcup_{o \in O} \nu(o)(u_1)) \wedge appear(\nu(o)(u_1))$

A plural information state O satisfies (10c) if it extends an input assignment I with values for u_1 such that within each assignment, each individual in u_1 is a cat who appeared, and summing across assignments, there are two individuals in u_1.

The sum operator is also used for collective verbal predicates such as *meet* (11).

(11) a. Two cats met.

b.
$$\begin{array}{|l|}\hline u_1 \\ \hline \\ cat(u_1) \\ 2\text{-}atoms(\cup u_1) \\ meet(\cup u_1) \\ \\ \hline \end{array}$$

In each assignment, u_1 ranges over atomic cats: it is only by summing over the values of u_1 across assignments that we get a plurality. This is called 'discourse-level plurality' by Brasoveanu (2007: pp. 352–3). Plural CDRT also countenances domain-level pluralities, i.e., plural individuals inside one assignment; see Brasoveanu 2007: chapter 8 for discussion and motivation for the distinction. Domain-level pluralities play no role in our analysis.[2]

Cumulative readings are the default for predicates with two or more plural arguments, as in (12). This differs from the relational analyses of Sternefeld (1998) and Beck (2001), which obtain a cumulative reading through application of a cumulation operator to a predicate.

(12) a. Two cats ate three mice.

b.

$u_1\ u_2$
$cat(u_1)$ $2\text{-}atoms(\cup u_1)$ $mouse(u_2)$ $3\text{-}atoms(\cup u_2)$ $eat(u_1, u_2)$

c. $$\lambda I.\lambda O.I[u_1\ u_2]O \wedge \forall o \in O.cat(\nu(o)(u_1)) \\ \wedge 2\text{-}atoms(\bigcup_{o\in O} \nu(o)(u_1)) \wedge\ mouse(\nu(o)(u_2)) \\ \wedge 3\text{-}atoms(\bigcup_{o\in O} \nu(o)(u_2)) \wedge eat(\nu(o)(u_1), \nu(o)(u_2))$$

Here u_1 ranges over two cats, u_2 over three mice, and in each assignment it is true that u_1 ate u_2, so we get a cumulative reading.

There is of course also a distributive reading of (12a). For this we must introduce the notion of a subset $I_{|u=d}$ of assignments i in I that assign the individual d to the discourse referent u. This is defined in (13), from Dotlačil (2013: example (57)).

(13) $I_{|u=d} =_{def} \{i \in I \mid \nu(i)(u) = d\}$

2 This is in contrast to some other plural CDRT analyses which make more extensive use of domain-level pluralities, e.g., Henderson (2014), who uses domain-level plurality to enforce cardinality constraints. But on such an approach there is no straightforward account of cumulativity and reciprocity.

With this in place we can introduce Dotlačil's distributivity operator δ_u, which applies to a DRS K as in (14). We provide a revised treatment of distributivity in Section 2.3.

(14) Distribution over u (Dotlačil 2013: example (58)):

$$\delta_u(K) =_{def} \lambda I.\lambda O.(\bigcup_{i \in I} \nu(i)(u)) = (\bigcup_{o \in O} \nu(o)(u)) \\ \wedge \forall d \in (\bigcup_{i \in I} \nu(i)(u)).K(I_{|u=d})(O_{|u=d})$$

$\langle I, O \rangle$ satisfies $\delta_u(K)$ iff I and O have the same set of values for u and each equivalence class in the partition of I induced by $u = d$ satisfies K. The first condition is needed because I and O are otherwise never globally compared (see discussion below). The reading where the two cats ate three mice each is then as in (15).

(15) a. Two cats ate three mice.

b. $$\begin{array}{|l|}\hline u_1 \\ \hline cat(u_1) \\ 2\text{-}atoms(\cup u_1) \\ \hline\end{array} ; \delta_{u_1}\left(\begin{array}{|l|}\hline u_2 \\ \hline mouse(u_2) \\ 3\text{-}atoms(\cup u_2) \\ \hline\end{array} \right) ; \begin{array}{|l|}\hline \\ \hline eat(u_1, u_2) \\ \hline\end{array}$$

The first DRS introduces two cats cat_1 and cat_2 in u_1. Thus, we get two equivalence classes $S_{|u_1=cat_1}$ and $S_{|u_1=cat_2}$. Each of these serves as input to the second DRS, which updates them to $O_{|u_1=cat_1}$ and $O_{|u_1=cat_2}$ respectively, each differing from $S_{|u_1=cat_1}$ and $S_{|u_1=cat_2}$ only in the value of u_2, and such that in $O_{|u_1=cat_1}$, u_2 ranges over three mice eaten by cat_1 and in $O_{|u_1=cat_2}$, u_2 ranges over three mice eaten by cat_2.

Finally, we must make sure that the final output state O really is the union of $O_{|u_1=cat_1}$ and $O_{|u_1=cat_2}$, i.e., that O doesn't include any stray cats not in I as the value of u_1. This is what the first conjunct of (14) $(\bigcup_{i \in I} \nu(i)(u)) = (\bigcup_{o \in O} \nu(o)(u))$ does. A sample output plural information state satisfying (15) is given in (16), with output assignments $\{o_1, \ldots, o_6\}$.

(16)

	u_1	u_2
o_1	cat_1	$mouse_1$
o_2	cat_1	$mouse_2$
o_3	cat_1	$mouse_3$
o_4	cat_2	$mouse_4$
o_5	cat_2	$mouse_5$
o_6	cat_2	$mouse_6$

2.2 Anaphora in Partial CDRT

(Plural) CDRT appeals to pre-semantic coindexation to introduce the *same* discourse referent for a pronoun and its antecedent, as shown in (17). This coarse-grained view of anaphoric relations makes it difficult to provide a satisfactory account of reciprocal scope ambiguities.[3]

(17) Anaphora as discourse referent reuse in (Plural) CDRT:

a. Chris^1 was happy. He$_1$ had won.

b.

u_1
$chris(u_1)$ $happy(u_1)$ $won(u_1)$

In contrast, Partial CDRT (Haug 2014) assumes that a pronoun such as *he* contributes its own discourse referent and a condition that it must corefer with an antecedent, whose identity is supplied by pragmatics. Formally, this is represented by a function $\mathscr{A}$ mapping anaphoric expressions to their antecedents.

(18) Anaphoric relations in Partial CDRT:

a. Chris^1 was happy. He^2 had won.

3 We use superscript indices for NPs introducing new discourse referents and subscript indices for anaphora referring to those NPs.

b. $$\begin{array}{|l|}\hline u_1\ \bar{u}_2 \\ \hline \\ chris(u_1) \\ happy(u_1) \\ had.won(u_2) \\ \\ \hline \end{array}\ , \mathcal{A}(u_2) = u_1$$

c. $$\lambda i.\lambda o.\partial(i[u_1\ u_2]o) \wedge chris(\nu(o)(u_1)) \wedge happy(\nu(o)(u_1)) \\ \wedge had.won(\nu(o)(u_2)) \wedge\ \partial(\nu(o)(u_2) = \nu(o)(\mathcal{A}(u_2)))$$

The overbar on $\bar{u}_2$ in the DRS in (18b) abbreviates the requirement for u_2 to find an antecedent, stated explicitly in (18c) as $\partial(\nu(o)(u_2) = \nu(o)(\mathcal{A}(u_2)))$. ∂ is the presupposition connective of Beaver (1992), mapping True to True and other truth values to undefined. The condition $\mathcal{A}(u_2) = u_1$ resolving the pronoun *he* to its antecedent is supplied "on the side", not as part of the semantic content, because the grammar does not specify the antecedent of a pronoun like *he*; thus, the relation between *he* and *chris* is not reflected in the expression in (18c). Crucially, in a Partial CDRT setting a DRS containing an unresolved pronoun is interpretable, and its meaning can contribute to the process of resolving the anaphoric relation: as Haug (2014) points out, the predicate in an example like *It mooed* contributes the important information that the referent of *it* is a cow, which is not available if a sentence is only interpretable when all of its pronouns are resolved.

The semantic effect of the resolution $\mathcal{A}(u_2) = u_1$ only appears when we make the appropriate substitution in the final conjunct of (18c), which then becomes (19).

(19) $$\partial(\nu(o)(u_2) = \nu(o)(u_1))$$

This arises as part of the translation of (18b) and has the net effect that the anaphoric identity condition is interpreted in the DRS where the anaphoric discourse referent is introduced.

Haug's theory relies on *partial* assignments, which provide for a very natural notion of information growth: if assignments are partial we can model discourse referent introduction as *extension* of a state. As defined in (5) for Compositional DRT, $i[u]o$ is an equivalence relation partitioning the set of assignments, and its plural version $I[u]O$ defined in (6) inherits this behavior. But the more natural notion of discourse referent introduction is arguably asymmetric. And indeed van den Berg's original Dynamic Plural Logic was partial, although Brasoveanu's compositional version is not.

In the context of Partial CDRT, we recast $i[u_1]o$ as in (20), which intuitively says that i extends o with a value for u_1.

(20) $i[u_1]o$ in Partial CDRT (final version):

$$i[u_1]o =_{def} \neg\exists x.\nu(i)(u_1) = x \wedge \exists x.\nu(o)(u_1) = x \wedge \forall u.u \neq u_1 \\ \to \nu(i)(u) = \nu(o)(u)$$

We generalize this to the relation between sets of assignments $I[u_1]O$ in exactly the same way as in (6).

In fact, in the present setting, underspecification and the pragmatics of anaphoric relations are not directly relevant for our problem; rather, we are concerned with the semantics of reciprocals and the relation between a reciprocal and a predetermined antecedent. Thus, in the remainder of the paper we simplify by translating (19) back into the abbreviated representation as $u_2 \to u_1$ (encoding the presupposition that 'u_2 refers back to u_1'). This gives (21) as an abbreviation for (18b).

(21)
$$\begin{array}{|l|}\hline u_1\ u_2 \\ \hline chris(u_1) \\ happy(u_1) \\ won(u_2) \\ u_2 \to u_1 \\ \hline \end{array}$$

This abbreviation suppresses the pragmatically supplied $\mathscr{A}$ function that we used in (18b).[4] An advantage of the representation in (21) is that it brings to the fore the coreference condition associated with anaphora, which is the crucial contribution of partial CDRT to the analysis of reciprocal scope.

How are conditions like $u_2 \to u_1$ treated in a partial and *plural* CDRT setting? The singular case is straightforward: we simply assume that identity conditions, just like other conditions, are evaluated pointwise in each assignment, i.e., $u_2 \to u_1$ translates as $\partial(\forall s \in S.\nu(s)(u_2) = \nu(s)(u_1))$. The plural case is more interesting, especially in contexts when a distribution operator intervenes between the anaphor and its antecedent, as we now show.

4 However, the $\mathscr{A}$ function plays a role in our discussion of different reciprocal meanings in Section 6.

2.3 Plural anaphora and a new way of doing distribution

The Partial CDRT account of anaphora can be carried over to the plural case, as shown in (22). We continue to include superscript and subscript indices on the examples under discussion, although in the partial setting these merely serve to clarify the intended reading and (unlike in Dotlačil 2013) are not part of the input to semantics. Since anaphoric expressions now introduce their own discourse referents, they have both superscript and subscript indices.

(22) a. [Tracy and Chris]^1 were happy. They$^2_1$ had won.

b.
$$\begin{array}{|l|}\hline u_1\ u_2 \\ \hline tracy\text{-}and\text{-}chris(\cup u_1) \\ happy(u_1) \\ won(u_2) \\ u_2 \rightarrow u_1 \\ \hline \end{array}$$

c.

	u_1	u_2
o_1	*tracy*	*tracy*
o_2	*chris*	*chris*

The anaphoric equation $u_2 \rightarrow u_1$ ensures that the values of u_1 and u_2 are identical in each assignment and hence have the same quantificational dependencies on other discourse referents. We also assume that — just like other conditions — anaphoric equations can include $\cup$ (i.e., $\cup u_2 \rightarrow \cup u_1$). In that case, the anaphor does *not* inherit the quantificational dependencies of its antecedent, and we get a cumulative identity requirement, allowing a so-called crossed reading to which we return below.

However, complex issues arise in cases where anaphora interacts with distribution. Kamp & Reyle (1993: p. 325) discuss (23), which has two readings that are distributive on the subject. (There is also a group reading of the subject, which we ignore.)

(23) The lawyers^1 hired a secretary^2 they$^3_1$ liked.

a. Each lawyer hired a secretary who she liked.
b. Each lawyer hired a secretary who all the lawyers liked.

Our system can straightforwardly represent the reading in (23a) as (24b), with a sample output state in (24c).

(24) a. The lawyers^{1} hired a secretary^{2} they$^{3}_{1}$ liked. (reading (23a))

b. $$\begin{array}{|l|}\hline u_1 \\ \hline \\ \mathit{lawyer}(u_1) \\ \\ \hline \end{array}\ ; \delta_{u_1}\left(\begin{array}{|l|}\hline u_2\ u_3 \\ \hline \\ \mathit{secretary}(u_2) \\ 1\text{-}\mathit{atom}(\cup u_2) \\ u_3 \rightarrow u_1 \\ \mathit{like}(u_3, u_2) \\ \mathit{hire}(u_1, u_2) \\ \\ \hline \end{array} \right)$$

c.

	u_1	u_2	$\cup u_2$ under δ_{u_1}	u_3
o_1	lawyer_1	$\mathit{secretary}_1$	$\{\mathit{secretary}_1\}$	lawyer_1
o_2	lawyer_2	$\mathit{secretary}_2$	$\{\mathit{secretary}_2\}$	lawyer_2
o_3	lawyer_3	$\mathit{secretary}_3$	$\{\mathit{secretary}_3\}$	lawyer_3

However, there is no way to represent (23b): the second DRS is interpreted inside the distribution operator δ_{u_1}, i.e., piecewise for each value of u_1 (each lawyer), so that information about the total group of lawyers is unavailable. But that is exactly what we need to resolve the anaphor as in (23b).

This can be thought of as "distributional overkill": the distribution operator applies to the whole DRS in (24), whereas it is in fact only needed for the interpretation of the condition 1-*atom*$(\cup u_2)$ to ensure that the cardinality condition is interpreted relative to each lawyer. For the interpretation of other conditions as well as the introduction of the discourse referents u_2 and u_3, the distribution operator is without effect except for the antecedency relation, where it in fact hides information that should be available.

Within classical DRT, Kamp & Reyle (1993: p. 353) work around this problem by introducing a new discourse referent for the group of lawyers; Minor (2017: pp. 221–223) develops a similar solution within plural CDRT, where the distribution operator distributes over a copy of the relevant discourse referent, and Nouwen (2007) offers a stack-based solution within the framework of van Eijck (2001). All of these approaches introduce a new discourse referent/stack position merely to serve as a potential antecedent that will yield the intended reading. But intuitively, the two readings in (23) do not represent two different antecedents for *they*. The antecedent of *they* is *the lawyers* on both readings, but the anaphoric relationship is different: we have either bound anaphora or group coreference.

To preserve information about the total group we are distributing over inside the distribution operator, we need a more fine-grained approach to distributivity. We redefine DRSs as three-place relations between two plural information states I, O and a set of discourse referents Δ to distribute over, as shown in (25).[5]

(25)
$$\begin{array}{|l|}\hline u_1 \ \dots \ u_n \\ \hline \\ C_1 \\ \vdots \\ C_n \\ \\ \hline \end{array} =_{abbr} \lambda\Delta.\lambda I.\lambda O.I[u_1 \ \dots \ u_n]O \wedge C_1(O,\Delta),\dots,C_n(O,\Delta)$$

Whenever Δ contains a single discourse referent u we prefix δ_u to the DRS, and whenever Δ is empty we write a plain DRS. This preserves the notation we have used so far. Also, we require that I is defined for all the discourse referents in Δ.

Δ contains the information that is needed for distributive interpretation: given some information state $s_1 \in S$, we can form the equivalence class $[s_1]_\Delta$ of states in S that agree with s_1 on the inhabitants of all discourse referents in Δ.

(26) $[s_1]_\Delta =_{def} \{s \in S \mid \forall u \in \Delta.\nu(s)(u) = \nu(s_1)(u)\}$

We propose that the DRS itself is not interpreted distributively; instead we pass the whole information state S as well as the set of discourse referents Δ down to the conditions inside that DRS. Conditions, in turn, are interpreted as in (27).

(27) $R(u_1,\dots,u_m) =_{abbr} \lambda S.\lambda\Delta.\forall s \in S.R(u_1(s,[s]_\Delta),\dots,u_m(s,[s]_\Delta))$

We see that, as in standard plural CDRT, conditions are interpreted pointwise with respect to the assignments in S. However, they pass on two possible contexts of evaluation to the discourse referents they take as arguments: s and its equivalence class $[s]_\Delta$. Finally, individual and summed discourse referents are defined in (28).

(28) a. $u_i =_{abbr} \lambda s.\lambda S.\nu(s)(u_i)$
b. $\cup u_i =_{abbr} \lambda s.\lambda S.\bigcup_{s' \in S} \nu(s')(u_i)$

5 We require distribution over multiple discourse referents in our treatment of intensionality in Section 3.1.

That is, discourse referents take two arguments, a singular state s and a plural state S, generally the equivalence class $[s]_\Delta$. An individual discourse referent returns the value at s (and throws away S); a summed discourse referent returns the set of values under S (and throws away s). This yields the intended effect that distributivity is only relevant for sum discourse referents, where it is used to form the relevant equivalence class.[6]

Now, the available reading for the pronoun in (23b) shows that antecedence conditions *escape* the distribution operator. We therefore encode antecedence conditions as in (29), making the whole state S available for interpretation of the anaphoric relationship.

(29) $u_{anaph} \to u_{ant} \quad =_{abbr} \quad \lambda S.\lambda\Delta.\forall s \in S.u_{anaph}(s,[s]_\Delta) = u_{ant}(s,S)$

That is, we serve the whole state S to the antecedent discourse referent and not just the equivalence class $[s]_\Delta$. This means that (on the sum interpretation), the antecedent outscopes any distribution.

Bound anaphora (where there are no $\cup$ markers) is not affected by this change. The anaphoric equation $u_3 \to u_1$ from (24b) is interpreted as in (30).

(30) $$\begin{aligned}&\lambda S.\lambda\Delta.\forall s \in S.u_3(s,[s]_\Delta) = u_1(s,S)\\ &\qquad =_{abbr} \quad \lambda S.\lambda\Delta.\forall s \in S.\nu(u_3)(s) = \nu(u_1)(s)\end{aligned}$$

Here, Δ plays no role and u_3 and u_1 have the same inhabitants in every state; we still get the bound reading illustrated in (24c).

However, our treatment of anaphora in the context of our reinterpretation of distributivity makes it possible to capture the reading in (23b), in which *they* refers to the group of lawyers. Its representation is as in (31b), which is similar to (24) (since we are distributing on the group of lawyers), but with sum discourse referents in the antecedence conditions for the pronoun *they*. A sample output state is in (31c).

(31) a. The lawyers^1 hired a secretary^2 they$^3_1$ liked. (reading (23b))

6 A similarly restricted view of distributivity was proposed by Dotlačil (2011) with a different motivation (the absence of distribution over nominal predicates) and a different implementation (in team logic), but the same fundamental outlook: distributive interpretation should be assigned to argument positions, not to entire predicates.

b. $$\begin{array}{|l|}\hline u_1 \\ \hline \\ \mathit{lawyer}(u_1) \\ \\ \hline\end{array} \; ; \delta_{u_1}\left(\begin{array}{|l|}\hline u_2\ u_3 \\ \hline \\ \mathit{secretary}(u_2) \\ 1\text{-}\mathit{atom}(\cup u_2) \\ \cup u_3 \to \cup u_1 \\ \mathit{like}(u_3, u_2) \\ \mathit{hire}(u_1, u_2) \\ \\ \hline\end{array}\right)$$

c.

	u_1	u_2	$\cup u_2$ under δ_{u_1}	$\cup u_3$ in $\cup u_3 \to \cup u_1$ (see (37)-(38))
o_1	lawyer_1	$\mathit{secretary}_1$	$\{\mathit{secretary}_1\}$	$\{\mathit{lawyer}_1, \mathit{lawyer}_2, \mathit{lawyer}_3\}$
o_2	lawyer_2	$\mathit{secretary}_2$	$\{\mathit{secretary}_2\}$	$\{\mathit{lawyer}_1, \mathit{lawyer}_2, \mathit{lawyer}_3\}$
o_3	lawyer_3	$\mathit{secretary}_3$	$\{\mathit{secretary}_3\}$	$\{\mathit{lawyer}_1, \mathit{lawyer}_2, \mathit{lawyer}_3\}$

By (25), the second DRS abbreviates (32): in this example $\Delta = \{u_1\}$, and so each condition is interpreted by reference to two possible contexts of evaluation, O and $\{u_1\}$.

(32) $$\lambda I.\lambda O.I[u_2\ u_3]O \wedge \mathit{secretary}(u_2)(O, \{u_1\}) \wedge 1\text{-}\mathit{atom}(\cup u_2)(O, \{u_1\}) \wedge \cup\, u_3 \to \cup u_1(O, \{u_1\}) \wedge \ldots$$

$I[u_2\ u_3]O$ says that O differs from I in defining u_2 and u_3. This does not interact with distribution. $\mathit{secretary}(u_2)(O, \{u_1\})$ expands further as (33) by (27), which in turn becomes (34) by (28).

(33) $$\forall o \in O.\mathit{secretary}(u_2(o, [o]_{\{u_1\}}))$$

(34) $$\forall o \in O.\mathit{secretary}(v(o)(u_2))$$

In all assignments, the inhabitant of u_2 must be a secretary, exactly as in standard plural CDRT. More interesting is the next condition $1\text{-}\mathit{atom}(\cup u_2)$. The expansion is as in (35)–(36).

(35) $$\forall o \in O.1\text{-}\mathit{atom}(\cup u_2(o, [o]_{\{u_1\}}))$$

(36) $$\forall o \in O.1\text{-}\mathit{atom}(\textstyle\bigcup_{s \in [o]_{\{u_1\}}} v(s)(u_2))$$

As we sum the values of u_2 in each equivalence class defined by the value for u_1 (i.e., for each lawyer), we get one individual in u_2: in other words, one (potentially different) secretary for each lawyer.

Finally, the antecedence condition $\cup u_3 \to \cup u_1(O, \{u_1\})$ expands as in (37)–(38).

(37) $\forall o \in O. \cup u_3(o, [o]_{\{u_1\}}) = \cup u_1(o, O)$

(38) $\forall o \in O. \bigcup_{s \in [o]_{\{u_1\}}} \nu(s)(u_3) = \bigcup_{s \in O} \nu(s)(u_1)$

As we sum over the values in u_3 in each equivalence class defined by the value for u_1 (i.e., for each lawyer), we get the set of all values in u_1, i.e., all the lawyers. In this way, the antecedence condition "escapes" the distribution. When we now serve u_3 to the condition *like*(u_3, u_2), we correctly require that each of the lawyers liked each of the secretaries that were hired.

In sum, we have seen how the treatment of anaphora in Partial CDRT can be transferred to Plural CDRT. In the case of singular anaphora this is straightforward. Plural anaphora introduce some complications, but the result is in fact a better account of how anaphora behaves under distribution operators, without the need to copy discourse referents.

2.4 The PPCDRT analysis of reciprocity

Dotlačil (2013) proposes the Plural CDRT-based meaning in (39) for the reciprocal *each other*.[7] As discussed in Section 1, *each other* introduces a new discourse referent u_n which is anaphoric to another referent u_m, and requires that u_n and u_m are sum equal across assignments, but different in each assignment. In other words, reciprocity consists in cumulative identity between *each other* and its antecedent across assignments ($\cup u_m = \cup u_n$), combined with a distinctness condition within each assignment ($u_m \neq u_n$).

(39) Contribution of *each other*, Dotlačil (2013):

$$[\![\textit{each other}^n_m]\!] = \lambda P. \begin{array}{|l|}\hline u_n \\ \hline \cup u_m = \cup u_n \\ u_m \neq u_n \\ \hline \end{array} ; P(u_n)$$

7 In fact, Dotlačil (2013) formulates the semantics in terms of an explicit distributive operator, but the two definitions are equivalent.

For *Two girls saw each other*, this results in (40b).

(40) a. Two girls[1] saw each other$^2_1$.

b. $$\begin{array}{|l|}\hline u_1\ u_2 \\ \hline \\ 2\text{-}\mathit{atoms}(\cup u_1) \\ \mathit{girl}(u_1) \\ \cup u_1 = \cup u_2 \\ u_1 \neq u_2 \\ \mathit{see}(u_1, u_2) \\ \\ \hline \end{array}$$

In our Partial PCDRT setting, we update Dotlačil's proposal as follows:

(41) Contribution of *each other* in Partial PCDRT:

$$[\![\mathit{each\ other}]\!] = \lambda P. \begin{array}{|l|}\hline u \\ \hline \\ \partial(\cup u = \cup \mathit{c}\mathcal{A}(u)) \\ \partial(u \neq \mathit{c}\mathcal{A}(u)) \\ \\ \hline \end{array} ; P(u)$$

As discussed in Section 2.2, it is standard in Partial CDRT to treat the coreference requirements induced by anaphoricity (in this case, both group identity and individual distinctness) as presuppositions. That the distinctness criterion must be a presupposition was already argued by Beck (2001: Sections 4.2, 4.3), who observed that it cannot be the sole focus of negation; she contrasts this aspect of her analysis with Sternefeld's (1998) relational treatment, in which the distinctness criterion is asserted rather than presupposed, providing evidence that a presuppositional analysis fares better.

As observed in Section 2.2, we abstract away from the details of determining the reciprocal antecedent, so we continue to abbreviate (41) as in (42), where u_n is the reciprocal's discourse referent and u_m that of the antecedent.[8]

8 The presupposition operator is already a part of the → abbreviation, so it is overtly represented only on the distinctness criterion.

(42) $$\lambda P.\ \boxed{\begin{array}{l} u_n \\ \hline \cup u_n \rightarrow \cup u_m \\ \partial(u_n \neq u_m) \end{array}}\ ; P(u_n)$$

This proposal, like Dotlačil's, makes Weak Reciprocity the basic reading. We discuss in Section 6 how we can get other readings. But first we show how our analysis enables us to get a grip on reciprocal scope, which has generally been taken as an argument in favor of a quantificational analysis.

3 Reciprocal scope

As discussed in Section 1, Williams (1991) observes an interesting connection between the examples in (43) and (44):

(43) (= (2)) Two girls^1 thought that they$^2_1$ saw each other$^3_2$.

a. Each girl thought: "We saw each other." (narrow scope/group identity)

b. Each girl thought: "I saw her (= the other)." (wide scope/bound anaphora)

(44) (= (4)) Two girls^1 thought that they$^2_1$ would win.

a. Each girl thought: "We will win." (group identity)

b. Each girl thought: "I will win." (bound anaphora)

To our knowledge, no analysis based on the — to our mind compelling — intuition that this is one and the same ambiguity has ever been spelled out in detail. As we make the analysis precise, however, we will see that Williams' claim that the two ambiguities are *exactly* the same cannot be upheld. On the reading in (43b), the sentence does not report on a belief involving reciprocity, even if the embedded clause contains a reciprocal, and our analysis must capture that fact.

3.1 Intensionality

To deal with examples like (43) and (44) we must extend our framework with a treatment of attitude verbs. Following Brasoveanu (2007: chapter 7) we introduce discourse referents for worlds. We then intensionalize DRSs with a world argument which we assume, for simplicity, is transported to all conditions inside that DRS.[9] As usual, identity conditions (including anaphoric relations) are not world-dependent.

All quantificational dependencies in the evaluation world must carry over to *each* accessible world. Consider (45).

(45) Two boys^{1} told their$^{2}_{1}$ parents^{3} that they$^{4}_{2}$ loved them$^{5}_{3}$.

The matrix clause sets up a quantificational dependency between the two boys and their respective parents, and this must be transported to each evaluation world. That is, each boy must love both parents in each world compatible with what is said: it is not enough that he loves his mother in one world and his father in another. The same would hold if the intensional context contained anaphoric expressions reaching back to the previous discourse, outside the matrix clause.

We therefore require a notion of generalized distribution, i.e., distribution over *all* information states in some input assignment. We achieve this by taking Δ (the set of discourse referents we distribute over) to be all discourse referents defined in I. We represent generalized distribution by prefixing δ (without a subscript) to a DRS K and define the semantics of an attitude verb like *think* as in (46). Since discourse referents introduced inside attitude contexts are inaccessible to anaphoric uptake, we use an operator **T** to turn DRSs into conditions (tests). $\mathbf{T}(K)$ succeeds just in case the current information state can be extended with K.[10]

(46) $$\textit{think}(u,K) =_{def} \mathbf{T}\left(\delta\left(\begin{array}{|l|}\hline w \\ \hline \\ \mathbf{dox}_u(\cup w) \\ \\ \hline\end{array}\right);\delta_w(K_w)\right)$$

The idea is similar to that in Minor 2017: p. 403. We transport all quantificational dependencies from the world of evaluation to each doxastic alternative by introducing a world discourse referent w under the scope of generalized distribution, where w ranges over the doxastic alternatives of u for each value of u, using a predicate $\mathbf{dox}_u$ which is true of a set of worlds iff that set contains all and only the worlds that are epistemically accessible to u.

9 To deal with transparent readings we could allow non-local binding of (some) world variables as in Brasoveanu 2007.

10 Formally, $\mathbf{T}(K) =_{def} \lambda S.\exists S'.K(S)(S')$ where K is a DRS (potentially under distribution) and S and S' are plural information states.

Next we distribute over those worlds in the normal way, using the ordinary distribution operator δ_w, and check that the DRS K is true in each of those worlds. As a shorthand, we write this as K_w, where the (simplified) idea is that K_w is true in an assignment i iff all conditions in K are true in the world $\nu(i)(w)$.

First we consider the narrow scope reading in (47).

(47) a. Two girls thought that they would win.

(= Each girl thought: “We will win.”)

b. $$\begin{array}{|l|}\hline u_1 \\ \hline girl(u_1) \\ 2\text{-}atoms(\cup u_1) \\ think\left(u_1, \begin{array}{|l|}\hline u_2 \\ \hline \cup u_2 \rightarrow \cup u_1 \\ win(u_2) \\ \hline \end{array}\right) \\ \hline \end{array}$$

The discourse referent u_1 ranges over girls, and the discourse referent w ranges over each girl’s doxastic alternatives. Let us assume for simplicity that each girl has exactly one doxastic alternative. This yields (48).

(48)

	u_1	w
s_1	$girl_1$	$world_1$
s_2	$girl_2$	$world_2$

Next, we evaluate the embedded DRS relative to each world in w. This requires that we introduce a discourse referent u_2 for the subject pronoun *they*. By the antecedence condition $\cup u_2 \rightarrow \cup u_1$, within each equivalence class of input assignments defined by the value of w, u_2 ranges over the values of u_1 in the entire input state (the antecedent escapes distribution). This yields (49).

(49)

	u_1	w	u_2
s_{1a}	$girl_1$	$world_1$	$girl_1$
s_{1b}	$girl_1$	$world_1$	$girl_2$
s_{2a}	$girl_2$	$world_2$	$girl_1$
s_{2b}	$girl_2$	$world_2$	$girl_2$

Finally, $win(u_2)$ requires both $girl_1$ and $girl_2$ to win in $world_1$ and $world_2$. We could obtain the collective reading (each girl thought that they would win as a group) by changing $win(u_2)$ in (47) to $win(\cup u_2)$.

Consider now the wide scope version.

(50) a. Two girls thought that they would win.
(= Each girl thought: "I will win.")

b.

$$\begin{array}{|l|}\hline u_1 \\ \hline \mathit{girl}(u_1) \\ 2\text{-}\mathit{atoms}(\cup u_1) \\ \mathit{think}\left(u_1, \begin{array}{|l|}\hline u_2 \\ \hline u_2 \to u_1 \\ \mathit{win}(u_2) \\ \hline \end{array}\right) \\ \hline \end{array}$$

Again we get (48), but now u_2 must be identical to u_1 in each assignment. This gives us (51).

(51)

	u_1	w	u_2
s_1	$girl_1$	$world_1$	$girl_1$
s_2	$girl_2$	$world_2$	$girl_2$

This is true iff $girl_1$ and $girl_2$ win in worlds $world_1$ and $world_2$ respectively, as desired.

In sum, the difference between the two readings in (4) amounts to a difference in the way the anaphoric pronoun links to its antecedent. The group identity reading results when the pronoun refers back to the antecedent group ($\cup u_2 = \cup u_1$) whereas the bound anaphora reading results from a bound reading of the pronoun ($u_2 = u_1$).

3.2 Reciprocals in intensional contexts

Let us now see how this plays out when the embedded proposition contains a reciprocal. Consider first the narrow scope reading in (52).

(52) a. Two girls thought that they saw each other.
(= Each girl thought: "We saw each other.")

b.
$$
\begin{array}{|l|}
\hline
u_1 \\
\hline
\\
girl(u_1) \\
2\text{-}atoms(\cup u_1) \\
think\left(u_1, \begin{array}{|l|}
\hline
u_2\ u_3 \\
\hline
\\
\cup u_2 \rightarrow \cup u_1 \\
\cup u_3 \rightarrow \cup u_2 \\
\partial(u_3 \neq u_2) \\
see(u_2, u_3) \\
\\
\hline
\end{array}\right) \\
\\
\hline
\end{array}
$$

Processing this DRS up to the introduction of u_2 proceeds exactly as for (47) and results in (49). Next, we update with u_3 distributively for each world. By the conditions introduced by the reciprocal, the only way to do this is as in (53).

(53)

	u_1	w	u_2	u_3
s_{1a}	$girl_1$	$world_1$	$girl_1$	$girl_2$
s_{1b}	$girl_1$	$world_1$	$girl_2$	$girl_1$
s_{2a}	$girl_2$	$world_2$	$girl_1$	$girl_2$
s_{2b}	$girl_2$	$world_2$	$girl_2$	$girl_1$

This is true iff each girl sees the other within each world, the correct result.

Next, consider the wide scope reading in (54). In (47) we got this simply by changing to a bound reading of the pronoun. However, as noted by Sternefeld (1998), this does not work when the embedded proposition contains a reciprocal, because when the antecedent of the reciprocal has a bound reading, there is no plurality available for the reciprocal (consider the paraphrase "Each girl thought: 'I saw each other'"). Put another way, on the wide scope reading, the reported thought does not involve reciprocity: only the external speaker is responsible for the reciprocity. To get this effect we must interpret the reciprocal *de re*, i.e., lifted to the matrix DRS. For accessibility reasons, its antecedent must then also be lifted, yielding (54).

(54) a. Two girls thought that they saw each other.
(= Each girl thought: "I saw her.")

b.
$$\begin{array}{|l|}\hline u_1\ u_2\ u_3 \\ \hline \mathit{girl}(u_1) \\ 2\text{-}\mathit{atoms}(\cup u_1) \\ u_2 \to u_1 \\ \cup u_3 \to \cup u_2 \\ \partial(u_3 \neq u_2) \\ \mathit{think}\left(u_1, \begin{array}{|c|}\hline \\ \hline \mathit{see}(u_2, u_3) \\ \hline \end{array}\right) \\ \hline \end{array}$$

This DRS yields the information state in (55).

(55)

	u_1	u_2	u_3	w
o_1	$girl_1$	$girl_1$	$girl_2$	$world_1$
o_2	$girl_2$	$girl_2$	$girl_1$	$world_2$

(55) is true if $girl_1$ sees $girl_2$ in the doxastic alternative(s) of $girl_1$, and $girl_2$ sees $girl_1$ in the doxastic alternative(s) of $girl_2$, which is correct.

3.3 Crossed readings

Our account relies on two parameters to get the distinction between the two readings: the locus of the reciprocal (high or low), and the anaphoric relation between the reciprocal's antecedent and its antecedent in turn (bound or group coreference). This should in principle give us four possible readings, but as we saw, the bound reading of the reciprocal's antecedent cannot cooccur with a low locus for the reciprocal, because it does not make available the plurality that the reciprocal needs. But is the non-bound reading ever found in combination with a high locus for the reciprocal, i.e., can we get the reading in (56)?

(56)
$$\begin{array}{|l|}\hline u_1\ u_2\ u_3 \\ \hline \\ \mathit{girl}(u_1) \\ 2\text{-}\mathit{atoms}(\cup u_1) \\ \cup u_2 \to \cup u_1 \\ \cup u_3 \to \cup u_2 \\ \partial(u_3 \neq u_2) \\ \mathit{think}\left(u_1, \begin{array}{|l|}\hline \\ \hline \mathit{see}(u_2, u_3) \\ \\ \hline \end{array}\right) \\ \\ \hline \end{array}$$

The difference between (56) and (54) is that (56) can be true in a situation where *girl*$_1$ thought *girl*$_2$ saw *girl*$_1$ and vice versa. It has repeatedly been claimed in the literature that such "crossed" readings do not exist (Heim, Lasnik & May 1991, Dimitriadis 2000, LaTerza 2014). However, we believe (with Dotlačil (2010) and Dotlačil & Nilsen (2011)) that this claim is incorrect. (57)–(58) show attested examples of crossed readings.

(57) Jennifer Lawrence & Emma Stone Reveal *They Thought They Catfished Each Other* & More in Hilarious Joint Interview[11]

(58) Sometimes they are hesitant to become romantically involved because *they believe that they do not like each other*, because one of them already has a partner, or because of social pressures. [Wikipedia]

One question briefly brought up by LaTerza (2014: 181n3) is whether crossed readings are acceptable only when the embedded clause contains a reciprocal. (He attributes this claim to Dotlačil (2010), although Dotlačil actually argues that crossed readings are always possible.) Clearly, it is hard or impossible to get crossed readings for examples like (59)–(60).

(59) Tracy and Chris thought they were sick.

(60) Romney and Obama thought they would win.

11 http://www.shineon-media.com/2018/01/05/jennifer-lawrence-emma-stone-reveal-they-thought-they-catfished-each-other-more-in-hilarious-joint-interview/

Although we cannot offer quantitative data, our own corpus research experience suggests that it is in fact much harder to get a crossed reading in the absence of a reciprocal. (57)–(58) and similar examples were found quite easily, whereas an extensive search for similar patterns without a reciprocal yielded only one example, (61).

(61) *They both thought they died* and have thought of each other all this time.[12]

From our point of view it is not surprising that it is harder to get the crossed reading in this case. To get group coreference and hence a possible crossed reading, we must lift the pronoun to the main DRS, but in the absence of the reciprocal there is no independent motivation to do so. Further research on the lifting of pronouns may well reveal interesting constraints on the crossed reading.

3.4 Constraints on reciprocal scope

Williams (1991: p. 171) observes that even in wide scope readings, the reciprocal never scopes higher than the highest binder of the local antecedent, as shown in (62).

(62) Someone has thought that Tracy and Chris like each other.

a. ∃ > *each other* available: Someone has thought: "Tracy and Chris like each other."
b. *each other* > ∃ unavailable (Someone thinks Tracy likes Chris and someone (else) thinks that Chris likes Tracy.)

Each other also does not behave like a distributive quantifier with respect to other scope-taking items (Asudeh 1998: chapter 6).

(63) Tracy and Chris may beat everyone to the finish line.

a. ∀ > *may* available: For each participant, it is possible that Tracy and Chris will beat that participant to the finish line.
b. *may* > ∀ available: It is possible that Tracy and Chris will beat every participant to the finish line.

(64) #Tracy and Chris may beat each other to the finish line.

12 https://www.reddit.com/r/Bellarke/comments/b6m39p/bellarke_season_6/

a. **each other* > *may* unavailable (It is possible that Tracy will beat Chris to the finish line, and it is possible that Chris will beat Tracy to the finish line.)
b. #*may* > *each other* doesn't make sense (It is possible that Tracy will beat Chris and Chris will beat Tracy.)

These facts are surprising on quantificational analyses of reciprocity, where variation in scope of the reciprocal plays a central role, as observed by Williams (1991) and Asudeh (1998). By contrast, our analysis gets the facts right: even if we allow for a high locus of the reciprocal (and therefore also its antecedent), we do not get a wide scope reading for examples like (65).

(65) Someone has thought that they like each other.

Raising the reciprocal and its antecedent to the main DRS yields the representation in (66).

(66)
$$\begin{array}{|l|}\hline u_1\ u_2\ u_3 \\ \hline \\ person(u_1) \\ 1.atom(\cup u_1) \\ \cup u_3 \to \cup u_2 \\ \partial(u_3 \neq u_2) \\ think(u_1, \begin{array}{|c|}\hline \\ \hline like(u_2, u_3) \\ \hline \end{array}) \\ \\ \hline \end{array}$$

Assuming that *they* refers to Tracy and Chris, the first four conditions give us the information state in (67):

(67)

	u_1	u_2	u_3
s_1	$person_1$	*tracy*	*chris*
s_2	$person_1$	*chris*	*tracy*

To evaluate the *think*-condition, each assignment in (67) is updated with all the doxastic alternatives of $person_1$, where $person_1$ is some individual who has the reported thought. This yields the correct truth conditions where *someone* has the highest scope. The apparent scoping mechanism is parasitic on the anaphoric relation of the antecedent and therefore correctly constrained.

Next we consider the inability of reciprocals to scope over modals, as in (64), which only has the pragmatically strange reading that it is possible that Tracy and Chris beat each other. Allowing for a high locus for the reciprocal still does not give us a wide scope reading. The DRS is as in (68).

(68)
$$\begin{array}{|l|}\hline u_1\ u_2 \\ \hline \\ \textit{tracy-and-chris}(\cup u_1) \\ \cup u_1 \rightarrow \cup u_2 \\ \partial(u_2 \neq u_1) \\ \Diamond \begin{array}{|l|}\hline \\ \hline \\ \textit{beat}(u_1, u_2) \\ \\ \hline \end{array} \\ \\ \hline \end{array}$$

The first three conditions yield the information state in (69).

(69)

	u_1	u_2
o_1	*tracy*	*chris*
o_1	*chris*	*tracy*

We interpret $\Diamond$ in parallel to our interpretation of attitude verbs (see (46)), i.e., as in (70), where **acc** refers to the appropriate accessible worlds.[13]

(70)
$$\Diamond(K) =_{def} \mathbf{T}\left(\delta\left(\begin{array}{|l|}\hline w \\ \hline \\ w \in \mathbf{acc} \\ \\ \hline \end{array}\right); \delta_w(K_w)\right)$$

The modal condition requires that we expand each assignment with w ranging over all accessible worlds, so we correctly predict that each accessible world contains a contradiction: Tracy beats Chris and Chris beats Tracy.

These examples were presented by Williams (1991) and Asudeh (1998) as posing problems for quantificational analyses of reciprocity, and it is an

13 Since we do not provide an analysis of modal restriction and subordination, we simplify the treatment of modality in Brasoveanu 2007: chapter 7.

advantage of our analysis that we predict the right readings for them. Additional constraints are still needed, however. Consider example (71).

(71) Everyone thinks that two girls like each other.

Lifting the reciprocal and its antecedent above *everyone* correctly yields the reading that is there is a particular pair of girls such that everyone thinks they like each other. However, we must block the reading where the relation between *every* and *two girls* is cumulative, i.e., where everyone thinks either that $girl_1$ likes $girl_2$ or that $girl_2$ likes $girl_1$ and cumulatively they think that the two girls like each other. In fact, however, the problem is not restricted to examples including reciprocals, and the solution should follow from whatever explains the absence of a cumulative reading of the simple example in (72).[14]

(72) Everyone likes two girls.

Additional constraints related specifically to reciprocal scope may also be needed, though previous claims about scoping constraints do not always hold up to scrutiny. Bruening (2006) claims that reciprocals cannot escape islands, providing the following examples which he claims have only the narrow scope reading.

(73) a. Chris and Joseph will open a bottle if *they beat each other*.
b. We rejected the claim that *we are taller than each other*.

We agree that only the (weird) narrow scope reading is salient in these examples, but there does not seem to be a general problem with the reciprocal escaping syntactic islands. We found many examples of long distance readings across different kinds of adjunct clause boundaries:[15]

(74) a. It isn't necessary for Israelis and Palestinians to get misty-eyed when *they imagine each other's suffering* (though that might help). [NOW]
b. "…Rape is endemic in Congo," says Dr Lusi. "Tribes use rape to show that *they are stronger than each other, to humiliate each other*." [NOW]

14 For discussion of such examples in a version of plural CDRT with domain-level pluralities, see e.g., Minor 2017: Section 4.4 and references therein.

15 Examples annotated "NOW" come from Davies 2013.

Although we have no explanation for why a long distance reading is not salient in the structurally similar (73a), these examples show that there is no general ban on long distance reading across an adjunct clause boundary.[16]

Examples with a long distance reading across strong islands, such as the complex NP in (73b), seem much harder if not impossible to construct or find in corpora. A possible explanation may be that the lifting of the reciprocal and its antecedent is not possible out of a complex DP.

3.5 Scope: Conclusion

Our accounts yields a very natural treatment of reciprocal scope which to a large extent does justice to Williams's intuition that the ambiguities of (43) (*Two girls thought that they saw each other*) and (44) (*Two girls thought that they would win*) are the same. We do not overpredict scopal possibilities with regards to modals and other quantificational items, and we require no special machinery beyond what plural and partial CDRT offer. From plural CDRT we use the idea that conditions can be satisfied either distributively or collectively, and from partial CDRT we use the idea that anaphoric expressions introduce discourse referents that are linked to their antecedents via coreference presuppositions, to which the principle of distributive or collective satisfaction then applies.

Our theory does introduce an element that is reminiscent of the scopal theory, namely variation in the locus of interpretation of the reciprocal. However, we do so without introducing distribution over the reciprocal's antecedent group. For that reason, we preserve the advantages of relational theories, and we get the combined empirical coverage of quantificational and relational theories, as we now show.

4 Consequences of the analysis and comparison to other approaches

Our relational account solves a number of problems that plague theories which analyze reciprocity in terms of distributive quantification. Some of these problems have already been noted by Murray, Dotlaĉil, and others, while others have not to our knowledge been observed in previous work. Sternefeld (1998) and Beck (2001) also present analyses based on a relational

16 A reviewer speculates that similar constraints also hold for cumulative readings involving a plural noun phrase inside a strong island. We leave this potentially interesting connection for future work.

view of reciprocity, and their analyses have the same advantages over quantificational theories as our analysis in many cases — but not all, as we will see. We begin by sketching their analyses.

4.1 Sternefeld's and Beck's relational analyses

Sternefeld (1998) presents an analysis of (weak) reciprocity in terms of a cumulation operator that applies to predicates. He adopts the cumulation operator of Krifka (1989), as defined in (75), where $\oplus$ is a group-forming operator.

(75) For any relation R, let $^{**}R$ be the smallest relation such that $R \subseteq {}^{**}R$ and if $\langle a, b\rangle \in {}^{**}R$ and $\langle c, d\rangle \in {}^{**}R$, then $\langle a \oplus c, b \oplus d\rangle \in {}^{**}R$

With this operator, a weak reciprocal reading of a two-place relation is obtained by conjoining the original relation with a non-equality statement, cumulating over the result,[17] and serving the same plurality to both argument positions.

(76) (= Sternefeld 1998: (26b))
$\langle A, A\rangle \in {}^{**}\lambda x.\lambda y.R(x, y) \wedge x \neq y$

Beck's approach to weak reciprocity (Beck 2001) is similar to Sternefeld's: the reciprocal denotes "the other(s) of them", contributing a distinctness condition and a coreference condition, where the latter part raises out of the scope of the cumulation operator. However, unlike Sternefeld, Beck's proposal explicitly constructs a group denotation for the reciprocal with a *max* operator and deals with subgroup readings through *covers*. Her analysis is given in (77a), which simplifies to (77b) in the case where all covers consist of singularities.

(77) (= Beck 2001: (120a) and (120c))

a. $\langle A, A\rangle \in {}^{**}\lambda y \lambda x[Cov(x) \wedge Cov(y) \wedge R(x, max(^{*}\lambda z[Cov(z) \wedge \neg(z \circ x) \wedge z \leq y]))]$

b. $\langle A, A\rangle \in {}^{**}\lambda y \lambda x[R(x, y) \wedge \partial(y \neq x)]$

17 In fact, the operator approach to cumulativity needs several operators, one for each arity of the relation (Sternefeld 1998: p. 317), whereas the plural CDRT approach is general.

The *max* operator has the effect that the distinctness condition becomes a presupposition: if x and y are identical, the set of z's such that z is a part of y but does not overlap with x is empty and has no maximum.

Sternefeld's and Beck's approaches require some non-trivial operations at the syntax-semantics interface. For Sternefeld, the reciprocal consists of a referential plural NP with a non-identity statement adjoined; the NP raises out of VP (and hence out of the scope of the cumulation operator) but leaves behind the non-identity statement, which is intersected with the verbal relation. For Beck, the underlying structure is slightly different, but the effect is the same: the group identity condition raises by what she calls "a funny QR operation" (Beck 2001: p. 105) and leaves behind the distinctness condition. We think it is an architectural advantage of the plural CDRT approach that such operations are not needed, but in the following we focus on clear empirical differences between the analyses.

4.2 Reciprocal/reflexive underspecification

As discussed by Murray (2008), many languages express reciprocity and reflexivity by the same means, either a verbal affix (as in Cheyenne, the focus of Murray's paper) or an independent word (e.g., German *sich*, as well as many Slavic and Romance languages). Such constructions often license 'mixed' readings between reciprocity and reflexivity. Murray (2008) discusses the Cheyenne example in (78), which allows a reflexive construal, a reciprocal construal, or a mixed construal:

(78) Ka′ėškóne-ho é-axeen-ȧhtse-o′o
child-PL.AN 3-scratch.AN-ahte-3PL.AN

a. Some children scratched themselves. [reflexive construal]
b. Some children scratched each other. [reciprocal construal]
c. Some of the children scratched each other while others scratched themselves. [mixed construal]

Cable (2014: pp. 4–5) discusses similar German and Romance examples, showing that they are not ambiguous between a reciprocal and a reflexive meaning, but rather have a single, underspecified meaning.

As argued by Murray (2008), a cumulative analysis set in a plural dynamic logic easily accounts for reciprocal/reflexive underspecification if the underspecified reflexive/reciprocal construction has only the sum equality constraint and not the distinctness constraint, as shown in (79b). The underspecified reflexive/reciprocal meaning in (79b) requires each individual u_n in the group to participate in the relevant relation with u_m, but allows u_m to be either the same as u_n or a different member of the group. A similar treatment is also natural on the relational analyses of Sternefeld (1998), Beck (2001) and Dotlačil (2013), as well as our account.

(79) a. $[\![\mathit{RECIP}^n_m]\!] = \lambda P. \begin{array}{|l|}\hline u_n \\ \hline \cup u_n \to \cup u_m \\ \partial(u_m \neq u_n) \\ \hline \end{array} ; P(u_n)$

b. $[\![\mathit{REFL/RECIP}^n_m]\!] = \lambda P. \begin{array}{|l|}\hline u_n \\ \hline \cup u_n \to \cup u_m \\ \hline \end{array} ; P(u_n)$

Murray (2008) observes that for quantificational accounts of reciprocity, 'mixed' construals as in the Cheyenne example (78) are unexpected because there are no common meaning components between reflexivity and reciprocity, let alone a way of providing an underspecified semantics.

4.3 Distributive and cumulative readings

Williams (1991) observes that reciprocals pattern with plurals rather than with quantifiers in the availability of distributive readings. As further discussed by Asudeh (1998) and corroborated by Dotlačil (2013) through acceptability judgment experiments, reciprocals and plurals resist distributive readings in (some of) the same contexts, e.g., (80).

(80) a. They gave every patient #new noses/a new nose.
b. They gave the patients new noses/#a new nose.
c. They gave each other new noses/#a new nose.

Similarly, cumulative readings are possible with plurals and reciprocals, but not with distributive quantifiers (81).

(81) a. Two children gave their parents six presents.
(cumulative reading available: six presents total)

b. Two children gave each other six presents. (cumulative reading available)

c. Two children gave every classmate six presents. (cumulative reading not available)

Dotlačil (2013) observes that on an quantificational analysis of reciprocity, it is mysterious that reciprocals pattern with plurals rather than quantifiers with respect to distributive and cumulative readings.

As pointed out by Dotlačil (2013: 460–464 and elsewhere), the relational analysis derives the cumulative reading as a default for reciprocal sentences as well as other plural predicates. (82b) shows a DRS for example (82a), with a sample verifying output state (among many) in (82c).

(82) a. Two children gave each other six presents.

b.
$$\boxed{\begin{array}{l} u_1\ u_2\ u_3 \\ \hline \\ 2\text{-}atoms(\cup u_1) \\ child(u_1) \\ \cup u_2 \rightarrow \cup u_1 \\ \partial(u_1 \neq u_2) \\ presents(u_3) \\ 6\text{-}atoms(\cup u_3) \\ give(u_1, u_2, u_3) \\ \\ \end{array}}$$

c.

	u_1	u_2	u_3
o_1	$child_1$	$child_2$	$present_1$
o_2	$child_1$	$child_2$	$present_2$
o_3	$child_1$	$child_2$	$present_3$
o_4	$child_2$	$child_1$	$present_4$
o_5	$child_2$	$child_1$	$present_5$
o_6	$child_2$	$child_1$	$present_6$

Sternefeld (1998) and Beck (2001) can also get this reading, although they would require a special three-place cumulation operator (Sternefeld 1998: p. 317). If *A* is the two children and *B* the six presents, the representation is as in (83) (with Beck's presuppositional analysis of the distinctness condition).

(83) Possible treatment of cumulative reading on the approach of Beck/Sternefeld:
$\langle A, B, A \rangle \in {}^{***}\lambda z \lambda y \lambda x[give(x, y, z) \wedge \partial(y \neq x)]$

4.4 Multiple reciprocal relations

A single clause can contain multiple reciprocals, as shown in (84). Moreover, such examples are ambiguous. Either both reciprocals take the subject as their antecedent, yielding reading (84a); or the second reciprocal takes the first one as its antecedent, yielding reading (84b).

(84) Tracy and Chris gave each other pictures of each other.
  a. Tracy gave Chris a picture of Chris, and Chris gave Tracy a picture of Tracy.
  b. Tracy gave Chris a picture of Tracy, and Chris gave Tracy a picture of Chris.

In example (84), two different reciprocal relations are established, one for each reciprocal expression. Dotlačil (2013: pp. 458–459) shows that a relational analysis in the setting of Plural CDRT provides a simple account of multiple reciprocals in examples like (85a). (85b) gives the analysis of (85a) on the reading where the second reciprocal takes the first one as its antecedent.

(85) a. Two girls^1 gave [each other]$^2_1$ pictures^3 of [each other]$^4_2$.

  b.
$$\begin{array}{|l|}\hline u_1\ u_2\ u_3\ u_4 \\ \hline \\ \text{2-}\mathit{atoms}(\cup u_1)) \\ \mathit{girl}(u_1) \\ \cup u_2 \rightarrow \cup u_1 \\ \partial(u_1 \neq u_2) \\ \cup u_4 \rightarrow \cup u_3 \\ \partial(u_2 \neq u_4) \\ \mathit{picture.of}(u_3, u_4) \\ \mathit{give}(u_1, u_2, u_3) \\ \\ \hline \end{array}$$

  c.

	u_1	u_2	u_3	u_4
o_1	$girl_1$	$girl_2$	pic_1	$girl_1$
o_2	$girl_2$	$girl_1$	pic_2	$girl_2$

The other reading, where both reciprocals takes the subject as their antecedent, is also unproblematic.

(86) a. Two girls[1] gave [each other]$^2_1$ pictures[3] of [each other]$^4_1$.

b.
$$\begin{array}{|l|}\hline u_1\ u_2\ u_3\ u_4 \\ \hline \\ \textit{2-atoms}(\cup u_1) \\ \textit{girl}(u_1) \\ \cup u_2 \rightarrow \cup u_1 \\ \partial(u_1 \neq u_2) \\ \cup u_4 \rightarrow \cup u_1 \\ \partial(u_1 \neq u_4) \\ \textit{picture.of}(u_3, u_4) \\ \textit{give}(u_1, u_2, u_3) \\ \\ \hline \end{array}$$

c.

	u_1	u_2	u_3	u_4
o_1	$girl_1$	$girl_2$	pic_1	$girl_2$
o_2	$girl_2$	$girl_1$	pic_2	$girl_1$

Williams (1991) observes that quantificational analyses have difficulties with English examples with multiple reciprocals (see also Dotlačil 2013). The general problem is that it is not possible for more than one distributive operator to apply to a single plural argument. If the antecedent of the second reciprocal in (84) is the first reciprocal, we encounter a different problem, since on a distributive analysis reciprocals don't denote a group, which the second reciprocal needs for its interpretation.

Neither Sternefeld nor Beck discusses examples with multiple reciprocals, but we speculate that they could be analyzed as in (87).

(87) Possible treatment of multiple reciprocals by Beck/Sternefeld:

a. $\langle A, A, A\rangle \in {}^{***}\lambda x.\lambda y.\lambda z.\textit{give-pics-of}(x, y, z) \wedge x \neq y \wedge y \neq z$

b. $\langle A, A, A\rangle \in {}^{***}\lambda x.\lambda y.\lambda z.\textit{give-pics-of}(x, y, z) \wedge x \neq y \wedge x \neq z$

(87a) would represent the reading in (85) and (87b) that in (86). It is not entirely clear how the syntax-semantics interface should be set up to get the right binding patterns; in the absence of a discussion by Beck or Sternefeld, we do not speculate further on how they would treat these cases.

4.5 Readings involving subgroups

Dalrymple et al. (1998) present the examples in (88), where each member of the group participates in the relevant relation with the combined remainder of the group.

(88) a. The gravitational fields of the Earth, the Sun and the Moon cancel each other out.
b. The forks are propped against each other.

In (88a), for example, the gravitational field of the Earth is canceled out by the combined effect of the gravitational field of the Sun and the Moon, and similarly for the other members of the group. A natural reading of example (88b) is that each fork is supported by the group containing all the others. These examples show that the reciprocal relation can hold between an individual and a subgroup, which is problematic for analyses where the reciprocal introduces distribution down to atoms.

Beck (2001: p. 94) notes that such examples are also problematic for Sternefeld, because the reciprocal does not denote a group on his analysis. Beck analyzes them as a subcase of strong reciprocity, which for her involves distribution on both the reciprocal and its antecedent, as in (89). $A - x$ denotes the antecedent group minus x.

(89) Strong reciprocity according to Beck (2001: (81b))
$A \in {}^*\lambda x[A - x \in {}^*\lambda y[Rxy]]$

If we leave out distribution on the reciprocal, we get (90), which seems right for examples like (88).

(90) The subgroup reading according to Beck (2001: (84a))
$A \in {}^*\lambda x[R(x, A - x)]$

However, it is debatable whether this kind of reading should be treated as a special kind of strong reciprocity. Although it is natural in (90) that each fork is supported by all the other forks, corpus data show that in many contexts, it is enough that each member of the reciprocal group bears the reciprocal relation to a group consisting of some but not all the remaining members.

(91) [So how would you be different from people who have grown up in areas with lots of Indians?] … I think the ones *who've grown up sur-*

rounded by each other … they end up having Indian accents almost, …
(Twamley 2014: p. 35)

A natural reading of (91) is that each Indian is surrounded by a group of other Indians, but not necessarily all of them.

In contrast, our analysis treats the relevant reading as a special case of weak reciprocity. That is, for (88), we get the weaker reading that each fork is supported by a group containing one or more of the other forks — possibly all of them, as may indeed be the most natural reading here, but not necessarily, as we see from example (91). The analysis is shown in (92), where the second argument of the *support* relation is $\cup u_2$.

(92)
$$\begin{array}{|l|}\hline u_1\ u_2 \\ \hline \\ \mathit{fork}(u_1) \\ \cup u_2 \to \cup u_1 \\ \partial(u_1 \neq u_2) \\ \\ \hline \end{array} \; ; \delta_{u_1}\left(\begin{array}{|l|}\hline \\ \hline \\ \mathit{support}(u_1, \cup u_2) \\ \\ \hline \end{array} \right)$$

Assuming there are three forks, (92) is compatible with a plural information state containing only the assignments in (93), but also with assignments with "more rows" so that $\cup u_2$ under δ_{u_1} would include the two other forks for each value of u_1.

(93)

	u_1	u_2	$\cup u_2$ under δ_{u_1}
o_1	fork_1	fork_2	$\{\mathit{fork}_2\}$
o_2	fork_2	fork_3	$\{\mathit{fork}_3\}$
o_3	fork_3	fork_1	$\{\mathit{fork}_1\}$

4.6 Collective readings

Dotlačil (2013: p. 433) shows that the antecedent of the reciprocal can receive a collective reading (94).

(94) The sailors have worked together on each other's ships.

In such cases, there seems to be no reciprocity involved: (94) can be paraphrased as "The sailors have worked together, and this took place on the ships of each of them". Similar naturally occurring examples are easily found:

(95) a. *They have rarely appeared together on each other's social media accounts* and in paparazzi shots. [NOW]

b. The Craft Cottage was born in 1967, when *local artists would gather in each other's homes* to feed off their colleagues' inspiration… [NOW]

Dotlačil (2013: pp. 455–458) demonstrates that in a Plural CDRT setting, example (94) receives a straightforward analysis, shown in (96), with the verifying information state in (96c), assuming there are three sailors.

(96) a. The sailors have worked together on each other's ships.

b.
$$\begin{array}{|l|}\hline u_1\ u_2\ u_3 \\ \hline \\ \mathit{sailor}(u_1) \\ \mathit{work.together}(\cup u_1) \\ \mathit{on}(u_1, u_2) \\ \mathit{ship.of}(u_2, u_3) \\ \cup u_3 \rightarrow \cup u_1 \\ \partial(u_1 \neq u_3) \\ \\ \hline \end{array}$$

c.

	u_1	$\cup u_1$	u_2	u_3
o_1	sailor_1	$\{\mathit{sailor}_1, \mathit{sailor}_2, \mathit{sailor}_3\}$	ship_1	sailor_2
o_2	sailor_2	$\{\mathit{sailor}_1, \mathit{sailor}_2, \mathit{sailor}_3\}$	ship_2	sailor_3
o_3	sailor_3	$\{\mathit{sailor}_1, \mathit{sailor}_2, \mathit{sailor}_3\}$	ship_3	sailor_1

Moreover, the Plural CDRT-based relational theory correctly predicts that there is no discernible reciprocal meaning in these cases, because the collective interpretation neutralizes the effect of the distinctness condition. In (96), u_1 and u_3 are distinct in each assignment, but because the argument $\cup u_1$ of the *work.together* predicate is interpreted collectively, we correctly predict that this does not matter.

Such examples are mysterious on an analysis of reciprocals involving quantification over individuals as well as on the relational analyses of Sternefeld (1998) and Beck (2001), since, as pointed out by Beck (2001: p. 93), distribution over the reciprocal's antecedent is a necessary component of the analysis.

4.7 Taking stock

Relational theories offer a straightforward account of a range of data which are problematic for scoping accounts. In our view, this puts relational theories at a clear advantage over quantificational theories. But not all relational theories are alike: using plural CDRT yields a very natural analysis of readings where either the reciprocal itself or its antecedent denotes a group, as we showed in Sections 4.5 and 4.6.

On the other hand, previous plural CDRT analysis do not handle scope ambiguities, whereas Sternefeld (and the quantificational analyses) did. The move to partial plural CDRT results in a theory that combines the empirical coverage of relational and quantificational theories. In the next section, we extend our theory with an account of quantified antecedents, which have so far been problematic for all theories of reciprocity.

5 Quantified antecedents

Our PPCDRT analysis of quantified antecedents for reciprocals builds on the PCDRT analysis of quantification proposed by Brasoveanu (2007).

Following Brasoveanu (2007: p. 211) we treat generalized quantifiers as externally dynamic, i.e., introducing discourse referents that can be picked up in the subsequent discourse. The quantifier introduces two discourse referents, corresponding to the maximal set of individuals satisfying the restrictor and the scope of the quantifier, and the two sets of individuals are provided as arguments to a (static) generalized quantifier.

To make this precise we must define a maximization operator. A variety of closely related operators have been proposed in plural dynamic semantics (see e.g., van den Berg 1996: pp. 82–3, Brasoveanu 2007: p. 219 and Dotlačil 2013: example (63)): the general idea is always that an update with $\mathbf{max}^u(K)$ fills the discourse referent u with as many values as possible such that K is true, but given our new definition of distribution, we must relativize this to the discourse referents in Δ.

(97) $\mathbf{max}^u(K) =_{def}$

$$\lambda I.\lambda O.\lambda\Delta.\left(\begin{array}{|c|}\hline u \\ \hline \\ \\ \\ \hline\end{array}\ ;\ K\right)(I)(O)(\Delta) \wedge \forall J.\left(\begin{array}{|c|}\hline u \\ \hline \\ \\ \\ \hline\end{array}\ ;\ K\right)(I)(J)(\Delta) \rightarrow$$
$$\forall J' \in J/\sim_\Delta.\,|\bigcup_{j'\in J'} \nu(j')(u)| \leq |\bigcup_{o\in O_{|J'}} \nu(o)(u)|$$

Here $\mathbf{max}^u(K)$ is a DRS, i.e., a relation between two plural information states I, O and a set of discourse referents Δ (see (25)), such that two conjuncts are satisfied. The first conjunct merely says that the DRS K is true of I, O, Δ. The second conjunct is the interesting one: it says that if a plural information state J makes K true in input context I and under distribution over Δ, then it must satisfy a certain cardinality condition. Intuitively the condition is that the set of values for u in J must be smaller than or equal to the set of values for u in O, thus guaranteeing that O contains the largest possible set of values for u.[18] However, distribution complicates the picture, because we must maximize u relative to all possible values for the discourse referents in Δ. Those values are fixed by $J/\sim_\Delta$, the equivalence classes over J induced by the values for the discourse referents in Δ. For any equivalence class J' in $J/\sim_\Delta$, there is a corresponding subset $O_{|J'} \subseteq O$ such that J' and $O_{|J'}$ agree on the values of the discourse referents in Δ, and these subsets also make up a partitioning of O.[19] So it is the set of values of u in each class J' in $J/\sim_\Delta$ and the corresponding equivalence classes $O_{|J'}$ that we compare, to make sure we get the maximal set of values for u relative to each valuation of the discourse referents in Δ.

Given this, the general scheme for the dynamic representation of generalized quantifiers is as in (98), where *DET* is the corresponding static quantifier. We focus here on quantifiers that are not obligatorily distributive with regards to their scope, as these are the ones that can easily be antecedents for reciprocals.

(98) $\mathbf{max}^u P(u); \mathbf{max}^{u' \sqsubseteq u} P'(u'); \mathit{DET}(u, u')$

We fill up u with the individuals that satisfy the restrictor property P. Next we fill up u' with the *subset* of u that satisfies the scope property P'. u and u' are the two discourse referents that a quantificational structure makes available for anaphoric uptake, corresponding to what Nouwen (2003: pp. 6–7) calls the maximal set (the whole set denoted by the restrictor) and the reference

18 This definition does not guarantee that there is a unique maximum. As observed by van den Berg (1996: p. 83), non-unique maxima can occur in cases of collective quantification — including, crucially for us, cases where a reciprocal relation holds over two sets A and B but not over their union.

19 This is because all discourse referents in Δ must be defined in the input state I so that two different extensions of I cannot differ in the values for those discourse referents.

set (the set denoted by the intersection of the scope and the restrictor).[20] Finally we check whether the relation expressed by the (static) determiner holds between the set of us and the set of u's.

Notice that u' is filled with a (possibly improper) subset of the values of u, i.e., the conservativity of generalized quantifiers is built into the definition to make sure that the discourse referent u' contains only individuals from the restrictor set. Technically, this is achieved by reusing the value of u for u' if the individual in question satisfies the scope property; if not, we leave u' undefined.[21]

We can now derive the representation of $\mathcal{Q}$ *people know each other*, where $\mathcal{Q}$ is some generalized quantifier, as in (99), where the antecedent is left unresolved in the style of partial CDRT (see Section 2.2).

(99) $$\mathbf{max}^{u_1}\;\begin{array}{|l|}\hline \\ \hline people(u_1)\\ \hline\end{array}\;;\;\mathbf{max}^{u_2\sqsubseteq u_1}\;\begin{array}{|l|}\hline u_3\\ \hline \cup u_3 \rightarrow \cup\mathcal{A}(u_3)\\ \partial(u_3 \neq \mathcal{A}(u_3))\\ know(u_2,u_3)\\ \hline\end{array}\;;\;\mathcal{Q}(u_1,u_2)$$

Clearly, *each other* must be bound by the subject $\mathcal{Q}$ *people*. But in a plural CDRT setting, the subject quantifier introduces *two* distinct discourse referents, u_1 and u_2 in (99).[22] This means that the discourse referent u_3 introduced by the reciprocal ranges either over the maximal set (all people), or over the reference set (all people that know u_3). In the following we first discuss examples which make salient these two possibilities, and we then argue that a sentence with a generalized quantifier binding a reciprocal is

20 Discourse reference to the complement set (i.e., the set-theoretic complement of the reference set relative to the maximal set) is sometimes possible, but Nouwen (2003: p. 79) argues that it always involves some sort of special inference.

21 In this we follow van den Berg (1996: p. 137) rather than Brasoveanu (2007: p. 215), who uses a dummy individual • that always yields falsity. We now need two distinct notions of undefinedness. In standard partial CDRT, *undefined* and *unused* discourse referents are equivalent: a discourse referent is undefined iff it has not been introduced in the discourse. But in the present set-up downward entailing quantifiers can introduce discourse referents for their scope that are undefined in all states. Since the notion of unused discourse referents plays no role here, we leave for future research how to best handle this.

22 This property of the plural CDRT analysis of generalized quantifiers is also exploited by Poschmann (2013) to account for ambiguities that arise when non-restrictive relative clauses are attached to quantificational heads.

strictly true only if it is true on *both* readings. This can be seen as a kind of supervaluationist account inspired by recent work on plurals (Križ 2015) and on donkey anaphora (Champollion, Bumford & Henderson 2019).[23] Such sentences have two precisifications according to whether the reciprocal ranges over the maximal set or the reference set. It is strictly true iff true under both precisifications, strictly false iff false under both precisifications, and otherwise undefined, in a sense that we explicate below.

5.1 The range of the reciprocal

Consider (100).

(100) This is a quiet street, *most people know each other* and say hello when you walk by. [NOW]

A natural reading of this example[24] is that there is a set D including a majority of the inhabitants of this street such that all of the members of D know all of the other members of D. This is in fact the reading we get if we let the reciprocal range over the reference set, yielding the representation in (101), where we have resolved the anaphoric reference $\mathscr{A}(u_3) = u_2$ and made the appropriate substitutions in (99).

(101)
$$\mathbf{max}^{u_1} \begin{array}{|l|}\hline \\ \hline people(u_1) \\ \hline \end{array} \; ; \mathbf{max}^{u_2 \sqsubseteq u_1} \begin{array}{|l|}\hline u_3 \\ \hline \cup u_3 \rightarrow \cup u_2 \\ \partial(u_3 \neq u_2) \\ know(u_2, u_3) \\ \hline \end{array} \; ; \mathbf{most}(u_1, u_2)$$

To see what information states support this DRS, let us assume the street has five inhabitants, $person_1$-$person_5$. (101) is true if there is a group consisting of more than half (say, 3) of the inhabitants, and each member of the group knows all of the other members, as in (102).

23 Jakub Dotlačil (p.c.) suggests that Križ's account of homogeneity might also work for homogeneity effects in reciprocal sentences: *Tracy, Chris and Mary don't know each other* means that *no* relation of knowing holds over this set. We leave this for future research.

24 In this section, we discuss only examples requiring Strong Reciprocity: each member of the group bears the relevant relation to every other member of the group. We discuss variation in reciprocal readings in Section 6.

(102)

u_1	u_2	u_3
$person_1$	$person_1$	$person_2$
$person_1$	$person_1$	$person_3$
$person_2$	$person_2$	$person_1$
$person_2$	$person_2$	$person_3$
$person_3$	$person_3$	$person_1$
$person_3$	$person_3$	$person_2$
$person_4$		
$person_5$		

This reading can be paraphrased as "the maximal subset Y of the set of all people such that *know-each-other*(Y) contains more than half of the people". It arises because (101) requires the reciprocal relation to hold over the reference set, which in turn must contain more than half of the members of the maximal set.

Consider now (103) from Dalrymple et al. (1998: p. 207).

(103) Its members are so class conscious that *few have spoken to each other*, lest they accidentally commit a social faux pas.

As Dalrymple et al. (1998) observe, this sentence "claims that few members have spoken to another one; it is clearly not a statement about the size of the largest group of members such that each pair of them have spoken." If the reciprocal ranges over the maximal set rather than the reference set, we get exactly this reading. Consider the representation in (104), where we have substituted $\mathscr{A}(u_3) = u_1$ in (99).

(104)
$$\mathbf{max}^{u_1}\ \begin{array}{|l|}\hline \ \\ \hline member(u_i) \\ \hline\end{array}\ ;\mathbf{max}^{u_2\sqsubseteq u_1}\ \begin{array}{|l|}\hline u_3 \\ \hline \cup u_3 \rightarrow \cup u_1 \\ \partial(u_3 \neq u_1) \\ speak\text{-}to(u_2, u_3) \\ \hline\end{array}\ ;\mathbf{few}(u_1, u_2)$$

In this case, it is easier to start with the values of u_1 and u_3, since this is fixed by the number of members in the model. There are no dependencies between u_1 and u_3 beyond $\cup u_1 \rightarrow \cup u_3$ and $\partial(u_3 \neq u_1)$ (in particular, the *speak-to* relation does not hold between u_1 and u_3). This yields the information state in (105) for u_1 and u_3 if there are five club members.

(105)

	u_1	u_3	u_2
o_1	$member_1$	$member_2$	
o_2	$member_1$	$member_3$	
o_3	$member_1$	$member_4$	
o_4	$member_1$	$member_5$	
o_5	$member_2$	$member_1$	
o_6	$member_2$	$member_3$	
o_7	$member_2$	$member_4$	
o_8	$member_2$	$member_5$	
o_9	$member_3$	$member_1$	
o_{10}	$member_3$	$member_2$	

	u_1	u_3	u_2
o_{11}	$member_3$	$member_4$	
o_{12}	$member_3$	$member_5$	
o_{13}	$member_4$	$member_1$	
o_{14}	$member_4$	$member_2$	
o_{15}	$member_4$	$member_3$	
o_{16}	$member_4$	$member_5$	
o_{17}	$member_5$	$member_1$	
o_{18}	$member_5$	$member_2$	
o_{19}	$member_5$	$member_3$	
o_{20}	$member_5$	$member_4$	

We update the u_2 column with a value identical to the u_1 column iff that person knows the person in the corresponding line of the u_3 column. Then we count the unique u_2s and compare with the unique u_1s. This yields the desired reading that (103) is true if the set of members that have spoken to at least one other member contains less than half of the members (on the proportional reading of *few*). That is, the maximal set reading yields an effect similar to weak reciprocity.

Notably, we derive this reading *without* appealing to additional claims about variation in reciprocal meanings. Dalrymple et al. (1998: p. 208), on the other hand, derive the reading by claiming that the downward entailing context enforces a weak reading for the reciprocal, which results in a strong reading for the overall sentence. But this is problematic because the behavior is not replicated in other downward entailing contexts, as we discuss in Section 6.1. By contrast, our account is based on properties of the quantificational structure itself and hence correctly predicts that the effect is limited to this context.

5.2 The empirical picture

We have seen one example (100) where the most natural reading involves the reciprocal ranging over the reference set, and one (103) where it most naturally ranges over the maximal set. What governs this choice?

In fact, the empirical picture is quite unclear and intuitions are not robust. Consider (106).

(106) Most members of this club know each other.

In their discussion of this example, Kamp & Reyle (1993: pp. 468–9) briefly consider two options: "a) the largest set *A* of club members such that for any two distinct elements *a* and *b* of *A*, *a* knows *b* and *b* knows *a*, consists of more than half of the members of the club; (b) the set of club members *a* for which there is some other member *b* such that *a* knows *b* and *b* knows *a* consists of more than half of the members of the club". These are exactly the two readings we derive by letting the reciprocal range over the reference set and the maximal set respectively.[25] Kamp and Reyle argue that reading a) is too strong, but suggest that reading b) may be too weak, and speculate that sentences of this type "do not *have* well-defined truth conditions, which apply to all situations in which the sentence can be used." A case in point is a situation where the club has 50 members, and there is one cluster of five people and seven clusters of four people such that all and only the people within one and the same cluster know each other. Kamp and Reyle suggest that the sentence is "arguably true" in this situation, but confess that it is not clear.

This indeterminacy is all the more surprising since the sentences we are looking at consist of well-understood components. It is perfectly clear what (107a) and (107b) mean, but much less clear what (107c) means.

(107) a. The members of this club know each other.
b. More than half of the members of this club know the chairman.
c. More than half of the members of this club know each other.

Thus, the difficulty in judging these examples arises from the interaction of the quantificational structure and the reciprocal. Our analysis predicts this, and locates the complexity in the two different ways of making precise the binding of *each other* by the quantifier.

There is a parallel here to donkey anaphora, which also involves an anaphoric dependency between elements in the restrictor and the scope of a quantificational structure which can be resolved in two ways (existential and universal, traditionally called weak and strong donkey anaphora). It has been known at least since Rooth (1987: p. 256) that this gives rise to unclear truth value judgments.

Champollion, Bumford & Henderson (2019), following an analysis by Križ (2015) of homogeneity effects in plurals, develop an analysis of this truth

25 Kamp and Reyle also briefly consider a third possibility where quantification is over pairs, but conclude that Roberts (1987) correctly ruled this out.

value uncertainty, where a donkey anaphor has two precisifications, the ∀ and the ∃ reading. A donkey sentence is true iff it is true under both readings, false iff false under both readings, and otherwise indeterminate. That yields the truth conditions in (108).

(108) ⟦Most farmers who own a donkey beat it.⟧ =
  a. **True** if a majority of donkey-owning farmers beat all their donkeys.
  b. **False** if a majority of donkey-owning farmers beat none of their donkeys.
  c. **Neither** otherwise

The semantic truth value gap is not intended to reflect speakers' intuitions directly, but is used to compute a pragmatic truth value. In short, propositions *count as true* in worlds which resolve the current Question Under Discussion (QUD) in the same way as worlds where the proposition is strictly true. For example, suppose the QUD is how farmers let out their repressed anger.[26] Then (108) may count as true even if most farmers beat only a single donkey.

If we apply the same line of analysis to the ambiguity we have identified in reciprocals bound by a quantifier, we get an account which is strikingly in line with intuitions that have been expressed in the literature. We define the truth value of a sentence where a quantifier binds a reciprocal as in (109).

(109) a. **True** iff true when the reciprocal ranges over the maximal set and over the reference set
  b. **False** iff false when the reciprocal ranges over the maximal set and over the reference set
  c. **Neither** otherwise

As long as we restrict attention to readings in which each member of the reference set participates in the reciprocal relation, the reciprocal relation holds over the maximal set if it holds over the reference set. This means that in an upward entailing context, the reference set reading determines truth and the maximal set reading determines falsity; in a downward entailing context, the opposite is true.

This accounts for the intuition that the reciprocal reading in (100) (with an upward monotone quantifier) is stronger than the one in (103) (with a

26 This is reminiscent of the scenario discussed in Champollion, Bumford & Henderson (2019: p. 4) and attributed to Paolo Casalegno via Chierchia.

downward monotone quantifier). (110)–(111) summarize the truth conditions we derive for the two examples we have examined so far:

(110) Most members know each other

a. **True** if the maximal subset D of members such that *know-each-other*(D) is true contains a majority of the club members.
b. **False** if the set of members who know at least one other member contains less than half of the club members
c. **Neither** otherwise

(111) Few members know each other.

a. **True** if the maximal subset of members who know at least one other member contains less than half of the members
b. **False** if the maximal subset D of members such that *know-each-other(D)* is true contains more than half of the members
c. **Neither** otherwise

We have duality of *most* and *few* (on the proportional reading) in the sense that (110) is definitely true iff (111) is definitely false and vice versa. However, there are intermediate scenarios where both can count as true, depending on the question under discussion. These are exactly the kinds of scenarios Kamp and Reyle judged as "arguably true".

(112) and (113) show that context strongly influences the interpretation of reciprocal sentences with quantified antecedents; these examples exemplify intermediate scenarios, and are easily judged true even if they are clearly not strictly true.

(112) He added that current radio stations have unimaginative programming, and *most stations copy each other* and use basic programming formulas. [NOW]

(113) As recently as the 1990s, *most scientists found each other's work* by cracking open a journal that their university subscribed to and reading the articles in print. [NOW]

In (112), the second sentence elaborates on the first and explains *in what way* most stations have unimaginative programming, namely by copying other stations. It does not matter how many other stations they copy. Similarly, (113) is about how most scientists found work by other scientists in the 1990s. Therefore these sentences can be judged true in scenarios where (100) (*Most* *people know each other*) would not. In that example, the question under discussion is how socially cohesive a particular neighborhood is, and for that question it matters not just how many people know at least one other person, but also how many people they know.

Similar weak readings arise even with the quantifier *all*.

(114) 36-year-old Kimberley revealed: "Cheryl comes to me for advice — *all mums ask each other for advice* and share stories about their babies." [NOW]

At issue here is who mothers go to for advice, namely other mothers. It does not matter how many other mothers they ask for advice: the sentence is judged true even if not all mothers ask all other mothers for advice.

The examples in (115) further demonstrate the influence of context. Both examples involve the quantifier *many* and the predicate *resemble each other*, but differences in the context give rise to corresponding differences in the scenarios in which each is judged true. Example (115a) claims that the maximal subset of a set of genera contains many of the genera, a strong reading ruling out intermediate scenarios: this reading is reinforced by the subsequent list of characteristics of this group. In contrast, example (115b) is true if there are several clusters of ideas, with resemblance within each cluster, but no requirement that any one cluster constitutes a large proportion of the ideas.

(115) a. No Paleocene fossil has been unambiguously assigned to any living order of placental mammals, and *many genera resemble each other*: generalized robust, not very agile animals with long tails and all-purpose chewing teeth … [Wikipedia]

b. Think of it as a game of mix and match, with the end goal of putting the best parts of several ideas together to create more complex concepts. You'll probably notice that *many ideas start to resemble each other* — which is a good thing. Try combining them … [27]

5.3 Comparison to other proposals

We are aware of only two other accounts of reciprocals with quantified antecedents. Dalrymple et al. (1998) and Szymanik (2016) both analyze reci-

27 https://www.designkit.org/methods/30

procity as polyadic quantification. As we saw in Section 4, there are independent reasons to reject this approach to reciprocals. We now show that their analyses of reciprocals with quantified antecedents also gives rise to problems for quantificational analyses of reciprocity (in particular, the polyadic quantification view) that are avoided in our relational account.

The basic intuition behind the polyadic quantification approach to quantified antecedents is simple: in a structure $\mathcal{Q}(A)(R)$, with $\mathcal{Q}$ a determiner, A a restriction and R a reciprocal relation, a type mismatch arises because R is a relation rather than the property that the determiner expects as its second argument. Instead, if the determiner is upward monotone in its second argument (which we symbolize $\mathcal{Q}^{\uparrow}$), we apply $\mathcal{Q}^{\uparrow}(A)$ to some subset u of A such that the reciprocal relation holds over u, as in (116).

(116) $\mathcal{Q}^{\uparrow}(A)(R)$ is true iff $\exists u \subseteq A.R(u) \wedge \mathcal{Q}^{\uparrow}(A)(u)$

Unfortunately, this only works for upward entailing quantifiers. For determiners $\mathcal{Q}^{\downarrow}$ that are downward entailing in their second argument, we must say that $\mathcal{Q}^{\downarrow}(A)(u)$ holds for *every* subset u of A such that R holds over u (117).

(117) $\mathcal{Q}^{\downarrow}(A)(R)$ is true iff $\forall u \subseteq A.R(u) \rightarrow \mathcal{Q}^{\downarrow}(A)(u)$

Dalrymple et al. (1998: p. 201) provide a definition of Bounded Composition which unifies (116) and (117). Formal details aside, Bounded Composition requires that each *maximal* set satisfying the restrictor and the reciprocal relation also satisfies the quantifier. This is similar in spirit to our account which requires that the maximal subset of the restrictor satisfying the scope must also satisfy the quantifier. Some complications arise, though: it is also necessary to require that either there is a subset satisfying the reciprocal relation (for upward entailing quantifiers) or the empty set satisfies the quantifier (for a downward entailing quantifier).

Even with that in place, Bounded Composition makes some dubious predictions. As we have seen (e.g., in downward monotonic and non-monotic contexts as in (103)), requiring the reciprocal relation to hold over the reference set is too weak: we are not inclined to judge (103) (*few have spoken to each other*) true in a context where each member has spoken to, say, five other members, but the largest group u such that *speak-to-each-other*(u) holds contains less than half of the members. Dalrymple et al's solution to this is that the Strongest Meaning Hypothesis interacts with the downward entailing environment to strengthen the meaning for the whole sentence by requiring a weak reading for the reciprocal. However, as we show in Section 6.1, this behavior is not replicated in other downward entailing contexts.

Szymanik (2016) takes a different route: on his approach, the reciprocal and the quantifier combine into a single so-called 'Ramsey quantifier' via a process of reciprocal lifting. He then studies the computational complexity of evaluating the truth value of such quantified expressions in finite models. His claim is that whenever the result of combining a particular quantifier and a particular reciprocal reading is computationally intractable (i.e., requires exponential time), the reciprocal reading is relaxed so as to yield a computationally tractable quantifier. For example, the combination of *most* and strong reciprocity yields a quantifier of exponential complexity, and, so the claim goes, we shift to a weaker reciprocal interpretation in e.g., (118).

(118) Most members of parliament refer to each other indirectly.

However, Szymanik's account (like that of Dalrymple et al. 1998) does not explain why we see apparent weakening of the reciprocal reading in sentences with *all* such as (114), since the strong reciprocal lift of *all* is computationally tractable (Szymanik 2016: p. 134). We conclude that our account fits the data better than both previous accounts.

6 Different reciprocal meanings

It is well-known that reciprocals can receive different readings depending on the predicate.

(119) The children pointed at each other.

(120) The men know each other.

(119) requires each child to point and be pointed at by another child (Majewski 2014). On the other hand, (120) requires Strong Reciprocity (Langendoen 1978): each man knows all of the others. There are also intermediate readings (Dalrymple et al. 1998):

(121) Five Boston pitchers sat next to each other.

The truth conditions of (121) are arguably weaker than strong reciprocity (each pitcher does not have to sit next to all the others), but not as weak as

(119). It is not enough that each pitcher sits next to some other pitcher; they must be connected.

Weaker reciprocal meanings have also been proposed. Dalrymple et al. (1998) propose a reading which they call One-Way Weak Reciprocity, according to which every member of the group participates as the first argument of the reciprocal relation. Dalrymple et al. provide example (122) to illustrate this reading, claiming that it means that each pirate stared at another pirate.

(122) “The captain!” said the pirates, staring at each other in surprise.

Such examples are discussed at length by Beck (2001), who argues convincingly that such examples actually involve Weak Reciprocity, but with contextually governed weakening motivated by pragmatically induced covers. Another proposed weak reading is Inclusive Alternative Ordering (Kański 1987), according to which each member of the group participates in the reciprocal relation as either the first or the second argument. This reading is most clearly exemplified where the reciprocal relation cannot hold in both directions, as in (123).

(123) The plates are stacked on top of each other.

This reading is very weak, because not every plate is on top of another and not every plate is under another plate. It has been noted that such readings are not generally available: many languages do not have them at all, and languages that do have them often restrict them to certain predicates and/or cases where the cardinality of the group is large (Beck 2001, Evans et al. 2011). For that reason, we ignore examples illustrating Inclusive Alternative Ordering in the following.

The different readings of reciprocals and how they are constrained has been a focus of the literature since at least Fiengo & Lasnik (1973). It may seem that the existence of different reciprocal readings supports a quantificational approach to reciprocals, since that approach has been claimed to offer a natural locus for the ambiguity. Dalrymple et al. (1998) propose that the interpretation of reciprocals is governed by the Strongest Meaning Hypothesis, which determines which reciprocal quantifier applies in a given context:

(124) A reciprocal sentence S can be used felicitously in a context c, which supplies non-linguistic information I relevant to the reciprocal's interpretation, provided the set $\mathscr{I}_c$ has a member that entails every

> other one: $\mathscr{I}_c = \{p | p$ is consistent with I and p is an interpretation of S obtained by interpreting the reciprocal as one of the six quantifiers in…[28]$\}$ In that case, the use of S in c expresses the logically strongest proposition in $\mathscr{I}_c$.

The challenge for the relational analysis, then, is to find a similarly natural locus of variation that can yield the different readings, and the task we set ourselves here is to sketch an account of how this can be done. Consider example (125):

(125) a. The boys know each other.

b.
$$\begin{array}{|l|}\hline u_1\ u_2 \\ \hline \\ \mathit{boy}(u_1) \\ \cup u_2 \rightarrow \cup u_1 \\ \partial(u_2 \neq u_1) \\ \mathit{know}(u_1, u_2) \\ \\ \hline \end{array}$$

If there are three boys, (126a) is a minimal information state compatible with (125), while (126b) is the desired, strong reciprocal reading.

(126) a.

	u_1	u_2
o_1	boy_1	boy_2
o_2	boy_2	boy_3
o_3	boy_3	boy_1

b.

	u_1	u_2
o_1	boy_1	boy_2
o_2	boy_2	boy_3
o_3	boy_3	boy_1
o_4	boy_1	boy_3
o_5	boy_2	boy_1
o_6	boy_3	boy_2

What distinguishes (126b) from (126a) is that the anaphoric connection between the discourse referents u_1 and u_2 involves more pairs of individuals.

28 Dalrymple et al. (1998) here enumerate the six possible quantifier meanings they assign to the reciprocal.

Formally, we can associate an anaphoric discourse referent u with a set of pairs of individuals R_u as in (127).

(127) $\langle d, d' \rangle \in R_u \leftrightarrow \exists o \in O.\nu(o)(u) = d \wedge \nu(o)(\circ\mathcal{A}(u)) = d'$

(126b) makes R_{u_2} bigger than (126a). Intuitively, then, we regain the effects of the Strongest Meaning Hypothesis through a Maximize Anaphora principle.

(128) **Maximize Anaphora**: In interpreting a DRS K containing a discourse referent u introduced by a reciprocal with antecedent u' and a relation $\phi(u, u')$, maximize R_u as much as possible subject to the constraint that it is possible that $\phi(u, u')$ holds in K (given contextual knowledge).

We may think of Maximize Anaphora in terms of a continuous view: we simply add as many members to the relation as possible while remaining consistent with world knowledge about the relation, along the lines of the Maximal Interpretation Hypothesis advocated by Sabato & Winter (2012) for reciprocal interpretation (see also Winter 2001). But we could constrain the anaphoric relation in other ways; for example, to require either full minimization or full maximization of R_u, yielding weak and strong reciprocity respectively. Intermediate readings would then be analyzed as strong readings with a contextual restriction, following Beck (2001). The latter analysis may be less natural in the current setting, but the question of how to analyze examples whose requirements seem to fall between Strong Reciprocity and Weak Reciprocity is ultimately an empirical one. Our approach is also broadly compatible with the experimental investigation in Majewski 2014, who takes weak reciprocity as the starting point and argues that stronger readings arise as an effect of predicate type (stativity) and economy preferences. Finally, it would be possible to subject Maximize Anaphora to the constraint that $\phi(u, u')$ be a *typical* reciprocal situation rather than a *possible* one, along the lines explored in Poortman 2017, Poortman et al. 2018.

In fact, the application of Maximize Anaphora to reciprocals may be a special case of a more general principle operative in the interpretation of anaphora. As noted by Kadmon (1990) and others, anaphora is normally exhaustive. For example, *them* in (129) refers to *all* the sheep that Harry owns.

(129) a. Harry owns some sheep. John vaccinates them.

b.

$$\begin{array}{|l|}\hline u_1 u_2 u_3 u_4 \\ \hline \\ \textit{Harry}(u_1) \\ \textit{sheep}(u_2) \\ \textit{own}(u_1, u_2) \\ \textit{John}(u_3) \\ u_4 \rightarrow u_2 \\ \textit{vaccinate}(u_3, u_4) \\ \\ \hline \end{array}$$

In terms of the present framework, *some sheep* introduces a discourse referent that ranges over some but not necessarily all the sheep that Harry owns. But in the presence of the anaphor in the second sentence, we strongly prefer reference to all the sheep Harry owns, possibly because this maximizes the anaphoric connection. In the current setup we can think of this effect as follows: in cases of pronominal anaphora, R_u is a set of identity pairs $\{\langle sheep_1, sheep_1\rangle, \langle sheep_2, sheep_2\rangle, \ldots\}$. To maximize this set, the first discourse referent must range over as many sheep as possible, i.e., all the sheep that Harry owns.

6.1 Maximize Anaphora and the domain of strengthening

The Strongest Meaning Hypothesis in (124) requires that the proposition expressed by the "reciprocal sentence *S*" is consistent with the non-linguistic information available in the context. The reason for Dalrymple et al. (1998) to apply the Strongest Meaning Hypothesis at the level of the "reciprocal sentence" comes from downward monotone quantifiers (130)–(131), as discussed in Section 5:

(130) Its members are so class conscious that *few have spoken to each other*, lest they accidentally commit a social faux pas.

(131) No one even chats to each other.

A weak reading of the reciprocal in these cases correctly results in the strongest reading of the overall sentence. However, this effect is crucially *not* replicated in other downward entailing contexts, where the reciprocal does not take a quantified antecedent. As demonstrated by Sauerland (2012), application of the Strongest Meaning Hypothesis at the matrix level in examples

(132)–(133) produces the wrong reading; for example, in (132), it yields the incorrect meaning "If each team member knew some other team member in advance, they won".

(132) If the team members knew each other in advance, they won.

(133) No team whose members knew each other in advance lost.

In sum, we take the data to support the view that reciprocal interpretation is primarily sensitive to the local relation between the reciprocal and its antecedent, consistent with Maximize Anaphora.

6.2 Maximize Anaphora and multiple reciprocals

A second welcome prediction of Maximize Anaphora appears in contexts where we have multiple reciprocals. Consider (134) on the reading where the second *each other* takes the first as its argument.

(134) The classmates^{1} gave each other$^{2}_{1}$ pictures of each other$^{3}_{2}$.

According to Maximize Anaphora, we maximize each relation *pairwise*. That is, each classmate gave a picture to all the other classmates, and each classmate received pictures of all the others. This is consistent with one natural interpretation of (134), namely that each classmate gave pictures of themselves to all the other classmates. Crucially, pairwise maximization does not predict a preference for the reading with all *triples*, i.e., that each classmate gave pictures of everyone else to everyone else, and we believe that this is indeed not the most natural reading for this example.

6.3 Maximize Anaphora and reciprocal scope

Maximize Anaphora makes no prediction about the narrow/wide scope construal. This distinction in fact results from variation in the relationship between the pronoun which antecedes the reciprocal and that pronoun's antecedent in turn, so it is orthogonal to Maximize Anaphora as stated in (128). But we get some interesting predictions when the antecedent set has more than two individuals, as in (135).

(135) Tracy, Matty and Chris think they praised each other.

On the narrow construal, maximizing anaphora subject to world knowledge yields the reading that each of Tracy, Matty and Chris think that each of them praised the two others. On the wide construal, we get the information state in (136).

(136)

	u_1	u_2	u_3	w
o_1	*chris*	*chris*	*tracy*	$world_1$
o_2	*chris*	*chris*	*matty*	$world_1$
o_3	*tracy*	*tracy*	*chris*	$world_2$
o_4	*tracy*	*tracy*	*matty*	$world_2$
o_5	*matty*	*matty*	*chris*	$world_3$
o_6	*matty*	*matty*	*tracy*	$world_3$

That is, each of Tracy, Matty and Chris believes that she praised the two others. While there is little work on how the choice of reciprocal meaning interacts with wide scope readings, we think this is the right prediction.

The local application of Maximize Anaphora also yields the right interpretation in intensional contexts. Consider (137).

(137) Tracy believes that the team members held hands with each other.

Applying the Strongest Meaning Hypothesis at the matrix level produces the reading where Tracy believes that each team member held hands with all the other team members. (After all, she may believe that they have more than two hands.) Maximizing at the level of the local relation yields the more natural, weaker reading of the reciprocal. But (128) crucially constrains maximization by the possibility that $\phi(u, u')$ holds *in the DRS in which it appears*. If the context supports the inference that Tracy thinks the team members have more than two hands, we get a stronger reading of the reciprocal.

Our main goal in this section has been to show that the relational analysis of reciprocity provides a natural locus for the ambiguity of reciprocal sentences. We have shown that the anaphoric relation between the reciprocal and its antecedent provides such a locus, and that the principle of maximizing anaphoric relations provides a good starting point for the analysis, possibly in combination with other principles. There is therefore no reason to think that variation in reciprocal readings provides support for the quantificational approach.

7 Conclusion

We have argued that the relational view of reciprocity makes possible a comprehensive account of a large range of data on reciprocal sentences. It has been clear at least since Murray (2008) and Dotlačil (2013) that theories where the reciprocal induces distributivity down to atoms have problems with much of these data. Quantificational theories are of this kind, but some relational theories such as Sternefeld (1998) and Beck (2001) retain a notion of distributivity and run in to some of the same problems. By contrast, theories based on plural dynamic logic (Murray 2008, Dotlačil 2013) allow us to dissociate reciprocity and distributivity completely. However, these theories have so far lacked any account of reciprocal scope, which has been a standard argument for a quantificational approach.

We have presented a relational theory which includes a treatment of reciprocal scope, thereby combining the empirical coverage of relational and quantificational theories. We achieved this by combining a plural dynamic approach with the analysis of anaphora in partial CDRT. Our theory locates the scope effects in the type of anaphoric relation between the reciprocal's binder and its antecedent. This not only accounts for the scope effects, but also constrains them in a way that quantificational theories do not. Moreover, the theory requires no machinery that is not already present in plural and partial CDRT. The only major adaption that is needed is in the analysis of distribution; and this analysis is independently motivated, since it yields better results even when there is no reciprocal present.

Our more fine-grained analysis also yields a satisfactory account of reciprocals with quantified antecedents. Such sentences give rise to unclear truth value judgments, and we locate the cause for this in the ambiguity as to whether the reciprocal ranges over the quantifier's maximal set or reference set. Judgments are clear in situations where a sentence is true or false on both readings, but in many intermediate situations pragmatics play an important role. Our account also provides a solid basis for addressing the thorny problem of the distribution of reciprocal meanings, locating the ambiguity in the anaphoric relation between the reciprocal and its antecedent by appeal to a Maximize Anaphora principle.

We have dealt almost exclusively with data from English, a language where reciprocity is expressed with a pronoun. This is the case in many languages and, given the relational view, it is very natural to understand why this is so, whereas it is much less clear on the quantificational view. But other languages have other strategies for expressing reciprocity; we leave for future research how those expressions can be analyzed within a relational view.

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