

Asymmetric Agreement in Pronominal Anaphora

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Abstract. Abstract. Adjuncts contribute to the spatiotemporal anchoring of events and situations described by linguistic expressions, while arguments describe the participants of events and situations. We show how a deterministic parser, based on the recovery of asymmetric relations, enables the identification of adjuncts as possible antecedents to pronouns, whether they are located in the domain of the sentence or in the domain of the discourse. We suggest that Information technologies and Natural language processing more generally should rely on pronominal anaphora resolution based on asymmetric agreement in order to improve their performance.

Keywords. Parsing; asymmetric agreement; arguments; adjuncts; event structure, information extraction; pronominal anaphora resolution

1. Linguistic expressions, arguments and adjuncts

Facts from a variety of languages indicate that linguistic expressions cannot be equated with strings of characters or concatenation of words, but are formed of constituents in syntax-semantic relations. Certain constituents are arguments, or participants, of the event described by a verbal predicate. This is mainly the case for nominal constituents (DP). Other constituents identify the spatial and temporal dimensions of the event. This is the case for prepositional constituents (PP). In the examples in (1)-(3), the PPs *in Miami* and *on Monday* are adjuncts, whereas the DPs *the shareholders* and *the company* are arguments of the verbal predicate *sold*.

- (1) On Monday, the shareholders sold the company.
- (2) The shareholders sold the company in Miami.
- (3) The shareholders sold the company on Monday.

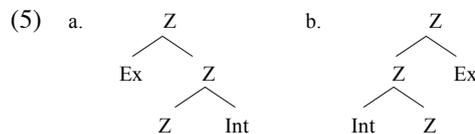
In this paper, we discuss the recovery of adjuncts to verbal projections by a parser and their identification as possible antecedents to pronouns in the discourse. We will start by differentiating argument structure from adjunct structure, as both arguments and adjuncts may qualify as possible antecedents to pronouns.

By argument structure we mean the structure of the arguments of a predicate, the internal argument (logical object) and the external argument (logical subject). Argument structure

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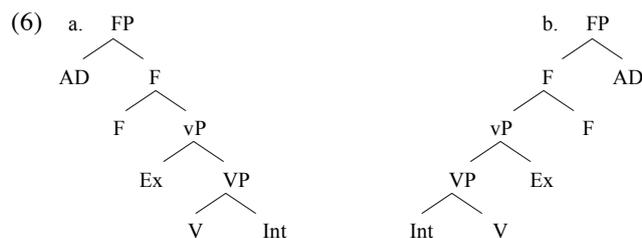
provides the syntactic basis of the semantic roles of the participants in an event or a situation. The precedence relation is not a reliable indicator of such relations, as constituents can be displaced from their canonical positions. Asymmetric c-command identifies the relation between two constituents in a binary branching tree, and distinguishes arguments in a hierarchical structure, independently of their linear order. Thus, given the definitions in (4), the external argument asymmetrically c-commands the internal argument in (5a, b).

- (4) a. *C-command*: X c-commands Y iff X and Y are categories and X excludes Y, and every category that dominates X dominates Y.
 b. *Asymmetric c-command*: X asymmetrically c-commands Y, if X c-commands Y and Y does not c-command X. [1]



By adjunct structure, we mean the extended projection of a verbal predicate (vP, VP) including projections such as PP and ADV. Adjunct structure provides the spatiotemporal anchoring of the event described by a verbal predicate. Here again, the precedence relation is not a reliable indicator of such relations, as prepositional phrases as well as adverbial constituents can be displaced from their canonical positions, as the previous examples in (1)-(3) illustrate.

As defined in (4) asymmetric c-command identifies the relation between two constituents in a binary branching tree. It provides a structural basis to distinguish adjuncts from arguments in a hierarchical structure independently of their linear order. Thus, in the trees in (6) the adjunct (AD) asymmetrically c-commands the arguments of the verbal predicate (vP, VP) that is, the external (Ex) argument and the internal (Int) argument of the verbal argument structure.



The recovery of adjuncts by a syntactic parser poses interesting challenges. In particular the fact that adjuncts seem to be less restricted than arguments with respect to their displacement properties has been largely discussed in linguistic theory [2], [3], [4], [5], [6], as well as in parsing theory, where questions related to their proper attachments arise [7], [8], [9], [10]. Efficient parsing of adjunct structures is a central concern for Natural Language Processing systems that aim to go beyond the analysis of sentences as strings of tokens and seek to approach human's cognitive ability to parse linguistic expressions naturally.

We assume that there is a close relation between Universal Grammar (UG) and the Universal Parser (UP). Namely, we assume the unified UG/UP Hypothesis, proposed in

[11], according to which the grammar generates asymmetric relations and the parser recovers the asymmetric relations deterministically. A consequence of the unified UG/UP Hypothesis is that it maintains a maximally simple relation between competence, i.e., the grammar, and performance, i.e., the parser, while ensuring a robust empirical coverage of linguistic variation.

The theory of UG that we will adopt is the Asymmetry Theory [12]. This theory includes the following main generic operations:²

- (7) *Shift* ((α, β))
Given two objects α and β , *Link* (α, β) creates a new object projected from α .
- (8) *Link* (α, β)
Given two objects α and β , *Link* (α, β) creates a new object where α and β are featurally related.
- (9) *Agree* (ϕ_1, ϕ_2)
Given two sets of features ϕ_1 and ϕ_2 , *Agree* holds between ϕ_1 and ϕ_2 iff ϕ_1 properly includes ϕ_2 , and the node dominating ϕ_1 asymmetrically c-commands the node dominating ϕ_2 .

The operation *Shift* combines two syntactic objects and creates a constituent. The operation *Link* relates two elements that have already undergone *Shift*. Both *Shift* and *Link* apply under *Agree*, which relies on featural and configurational asymmetry. *Agree* holds fully in the domain of the sentence; whereas only featural asymmetry holds in the domain of the discourse, as discussed in [13], [14] for discourse pronominal anaphora limited to constituents in argument positions.

This paper unfolds as follows. First, we discuss different approaches to syntactic parsing and present the main properties of deterministic asymmetry recovering parsing. Second, we discuss asymmetry-based works in pronominal anaphora resolution and show how it can be extended to adjunct structure. Finally, we conclude by discussing some consequences for Information Extraction and more generally for Natural Language Processing.

2. Parsing linguistic expressions

2.1 Asymmetry-based parsing

Notwithstanding the advantages of principle-based parsing systems [15], [16], there are two main problems associated with these systems as they were developed in the 1980s and early 1990s, mainly over-generation and speed. Over-generation is a consequence of the heterogeneity of Government and Binding principles [17], as well as their application to several levels of representations, e.g. D-structures (deep) and S-structures (surface), such that no singular principle was capable of sufficiently constraining the ultimate syntactic

² Asymmetry Theory also includes the operation *Flip*, which is part of the linearization of the constituents, as it reorders constituents to the right of their projection under certain conditions. See section 3 for discussion of the application of this operation to adjuncts.

structure of a phrase under analysis. [18] showed that hundreds of possible X-bar structures exist for the analysis of simple phrases, and the number of structures increases exponentially under the Theory of Movement. The slowness of parsing is a consequence of over-generation since the deduction chains linking the base principles to the surface forms are very long. Over-generation and speed problems can be significantly reduced by a system that incorporates a grammar based on the recovery of asymmetric relations [19], [20], [21], [22], and [23]. In this model, the computational procedure includes a central recursive operation, and a central agreement relation.

2.2 Deterministic Parsing

Deterministic parsing denotes the set of parsing algorithms that do not perform backtracking. That is, the parser does not go back to a previous stage to modify a structure that has been generated, and it does not look ahead a few more input items before making a cost effective decision at one stage of the algorithm. LR parsing [24], [25], is an example of deterministic parsing, contrary to chart parsing [26], [27], which is not deterministic. [28] showed that the Parsifal parser could overcome natural language ambiguity and still remains deterministic.

The study of strict left-to-right incremental parsing algorithms remains a relatively unexplored area of Natural Language Processing. Conventional algorithms for the recovery of phrase structure, e.g. LR, [24], [25], or Chart Parsing [29], are designed to operate on complete strings. That is, the input sentence to be analyzed is presented all at once. The output is one (or possibly more) parses covering the input sentence. In contrast, a left-to-right incremental parser processes the input a word at a time, producing one or more partial parses at each step. Each time a word is introduced, it extends or revises the analyses produced so far. A strict incremental parser is a parser that is monotonic in its output. That is, partial parses may only be augmented (no transformation or deletion is allowed) with the introduction of each succeeding word.

We focus on the deterministic parsing of linguistic expressions, and more specifically in this paper, on the deterministic parsing of adjuncts. Non-deterministic parsers return a list of solutions rather than just one solution. Deterministic parsers return only one solution containing only one parse tree and the remaining part of the input string.

2.3 Asymmetry Recovering Parser

Asymmetry recovering parsing denotes the set of parsing algorithms oriented towards the recovery of the asymmetric properties of natural languages. Computational implementations of asymmetric relations are available. The asymmetric c-command relation is part of Marcus's parser [28], as well as it is part of the framework of Principled Based Parsing [16], and of works on asymmetry and minimalism, including [11], [30], [31]. Figure 1 presents traces of an Asymmetry Recovering Parser implementing the operations of Asymmetry Theory [12].

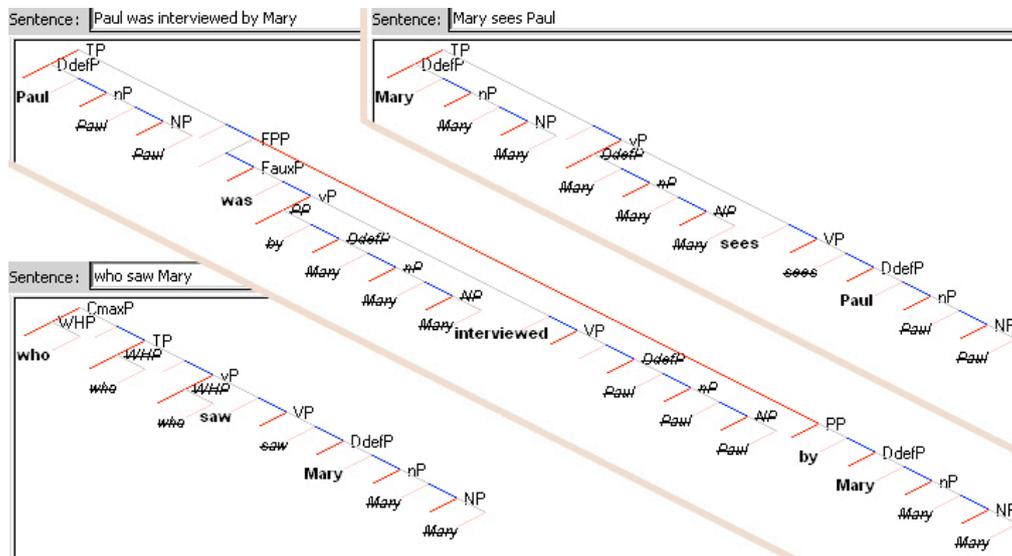


Figure 1. Traces of the Asymmetry Recovering Parser for English affirmative, passive, and wh-question.

The Asymmetry Recovering Parser [22], [23], is an LL deterministic parser recovering the syntactic structure of linguistic expressions. It performs left-to-right, top down analysis. It is based on a tightly constrained parsing system that is able to produce a monotonic output. The parser implements the Asymmetry Theory, [12], and thus it uses the asymmetrical properties of grammar for categorization, attachment, and dependencies. The parser also integrates what is particular to specific grammars, namely a lexicon and parameters of variation. It thus integrates parameters of variation in the form of a structured set of designated features. The lexicon is a structured group of lexical entries, each including a complete list of features that cannot be derived from independent properties of the grammar. The parser recovers from left to right the hierarchical structure, the ordering of constituents, and their relations. The system includes one Interface Interpretability Condition requiring that only elements in asymmetrical relations be interpreted by the external systems, conceptual and sensori-motor.

The following paragraph illustrates the syntactic analysis performed by the parser, the operations of which are oriented by the recovery of asymmetrical relations, whether they are operations of combination of constituents, operations of labeling or categorization, operations of right or left attachment of constituents, and operations specifying dependencies.

The linguistic expressions are parsed incrementally and constituents are built on the basis of the asymmetric agreement between the sets of features associated with lexical items. For example, in the determiner system, the French determiner *la* (the), has the formal features [D, uN, fem, sg], where u stands for unvalued, it projects a DP category [D, fem, sg], and the noun *physique* (physics), has the formal features [N, fem, sg], and projects a nominal phrase (NP) category [N, fem, sg]. The attachment of the determiner *la* to the NP *physique* will be done under feature asymmetry, in compliance with *Agree*, (9), the features of the determiner and the features of the noun are in a proper subset relation: the determiner, [D, uN, fem, sg], being the superset and the noun, [N, fem, sg], being the proper subset. The system will combine the D projection and the NP projection by the operation *Shift*. The

category formed is D, since, by definition, *Shift* creates a new category – contrary to the operation of adjunction. This constitutes an implementation of the asymmetry specific to *Shift*. Similar asymmetric agreement relations hold for the dependencies derived by the *Link* operation.

Furthermore, the linguistic expressions are parsed incrementally when the Interpretability Condition, according to which the parser analyzes elements in asymmetrical relations, is satisfied. Thus, if a word is to the left of another in a sequence, then either it is in an asymmetrical relation with this word, and the parsed constituent is accepted, or it is not, and the two words do not form a constituent. This provides a deterministic algorithm for the parser. The absence of backtracking assures the efficiency of the algorithm. The recovery of feature asymmetry significantly helps to reduce several cases of categorical ambiguity. For example, the determiner *la* is a definite article in the expression [*la physique*] (the physics), and a clitic pronoun in the expression [*Elle veut la connaître*] (she wants to know it). This form has a [D] feature, however the analyzer creates a head-complement structure in the case of [*la physique*], and an adjunct-head structure in the case of [*la connaître*]. In the latter case, the fact that verbal features are projected is a consequence of the fact that the merger of *la* (it) to the verb *connaître* (know) does not create a new category but allows the verb to satisfy its internal argument. The adjunct structure for the clitic pronoun *la* is created as soon as the parser recognizes it. The operation *Link* relates this pronoun to the object position, as soon as the verbal structure (vP) is recovered. Spatial and temporal adjuncts are also recovered as soon as they are fed into the parser. They are linked to the vP or to an argument position within the vP. The deterministic and asymmetry recovering mode of this parser increases the speed of analysis since categorization, merger and dependencies are created as early as possible in the course of the processing. This contrasts with the generate-and-test strategy wherein a structure cannot be accepted until several successive stages of heterogeneous principles verification are performed.

The Asymmetry Recovering Parser builds the predicate argument structure in the lower domain of the parse tree, (vp, VP), the adjunct structure is built in the higher domains (FP, TP), and the operator-variable structure in the highest propositional domain (CP). The CP domain is the locus of the recovery of discourse relations, such as the relation between a clause type operator and the sentence in the c-command domain of that operator. The TP domain is the locus of the recovery of displaced arguments, originating from the (vP, VP) domain. The parser not only recovers the positions of the silent copies left by displaced constituents, but it also recovers implicit arguments, the silent pronominals, PRO and Pro. It is extendable to languages other than English, provided the setting of the syntactic parameters of the languages under consideration. The lower layers of the parse tree, the (vP, VP) domain, are uniform across languages and the parametric variation in the distribution of the syntactic constituents is layered in the higher domains. The capacity of this parser to recover displaced constituents, as in the case of passives and wh-question, as well as covert arguments makes it a valuable tool for NLP, as discussed in [23]. The recovery of cover arguments for the sentence *John wants to study* is illustrated in Figure 2, which includes Pro and PRO, in addition to the copy left by displaced constituents, represented with strike threw.

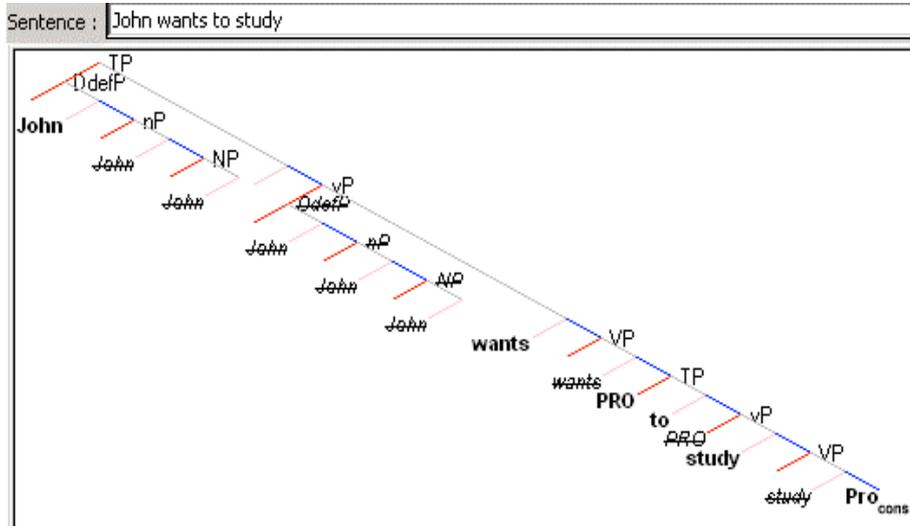


Figure 2. Trace of the Asymmetry Recovering Parser including covert arguments, PRO and Pro.

In the derived parse trees, the arguments of a predicate occupy canonical argument positions. That is, within the (vP, VP), the internal argument (Int) occupies the complement position of the verbal predicate, whether the verb is transitive or intransitive; the external argument of transitive verbs occupies the specifier of the vP. Arguments are generally nominal projections (DP) even though some verbal predicates select prepositional (PP) or propositional complements (CP). The external argument is displaced in the specifier of TP in active sentences, whereas it is the internal argument that is displaced in that position in passive and raising structures. The Asymmetry Recovering Parser also recovers the adjunct structure, in the higher domain of the parse tree. Prepositional phrases and adverbs are generated in FP projections that asymmetrically c-command the verbal domains (vP, VP). The linear order of the adjunct is derived by the operation *Flip*, which reorders a constituent to the right of a head under certain conditions. The operation *Flip* is proposed in [12], as applying in the component of the grammar which representations are interpreted by the sensori-motor system. *Flip* is part of the linearization of morphological and syntactic trees. In a morphological derivation, *M-Flip* (*T*) applies to a minimal tree *T* just in case the specifier of *T* has no PF features, that is, no features interpretable by the sensori-motor system. In a syntactic derivation, *S-Flip* (*T*) applies to a minimal tree *T* just in case the specifier of *T* has PF legible features. This operation reorders adjuncts located to the left of their projection chain to the right. The generic form of this operation is the following: *Flip* (*T*): Given a minimal tree *T*, *Flip* (*T*) is the tree obtained by creating the mirror image of *T*. Figure 3 and 4 present the results of the recovery of the PP adjuncts *on Monday* and *in Miami* in syntactic expressions by the parser. Figure 3 is the trace of the sentence *the shareholders sold the company on Monday*, and Figure 4 is the trace of the sentence *the shareholders sold the company in Miami*. In both cases, the parser generated the correct syntactic analysis.

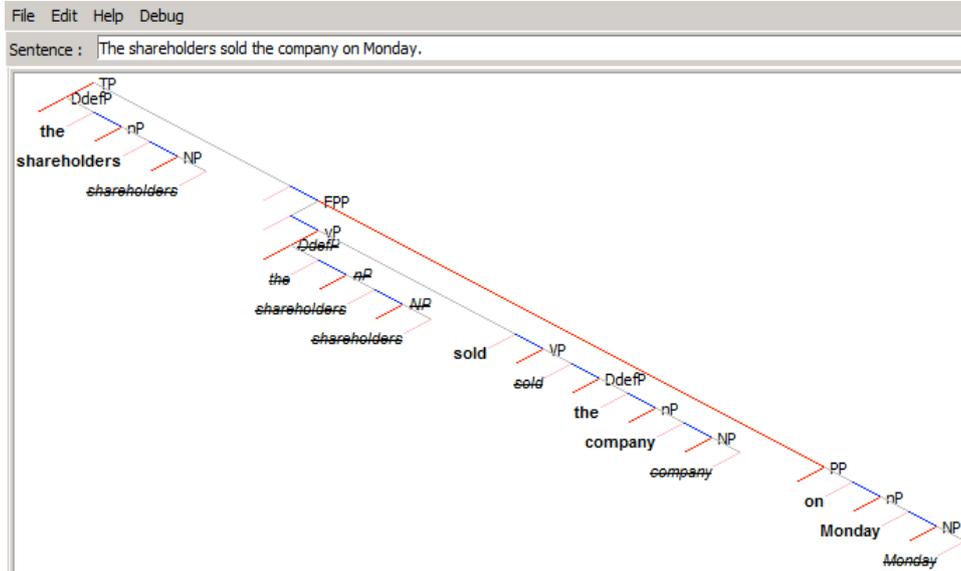


Figure 3. Trace of the Asymmetry Recovering Parser recovering a temporal adjunct.

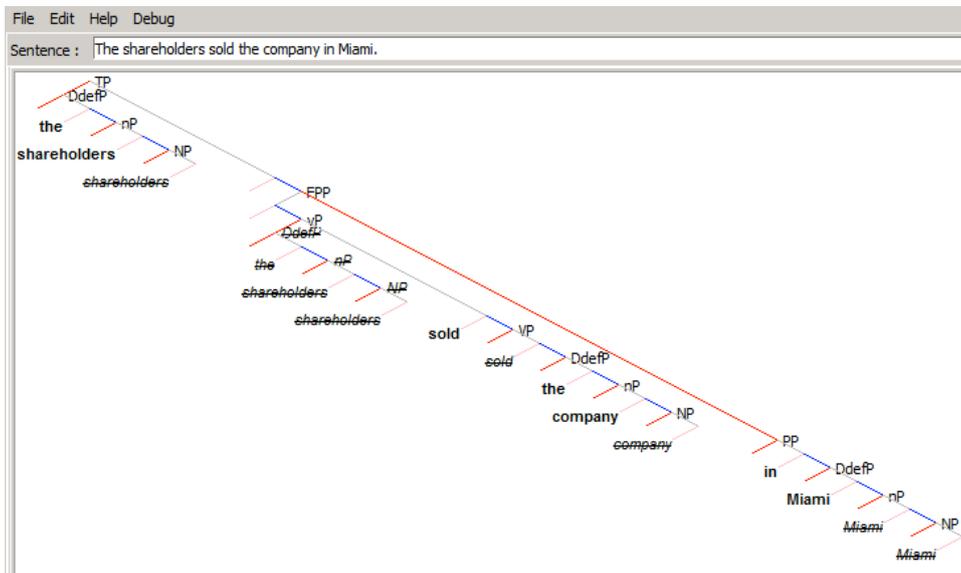


Figure 4. Trace of the Asymmetry Recovering Parser recovering a spatial adjunct.

As can be seen in the traces in Figure 3 and Figure 4, the prepositional adjuncts (FPP) *on Monday* and *in Miami* are attached to the left of the functional projection FPP, located between TP and vP. They are generated to the left of their projections FPP, and are flipped to the right of the FPP, given the *Flip* operation. Thus, in the parses in figures 3 and 4, they occur in sentence final position.

To summarize, in this section we discussed deterministic and asymmetry recovering parsing, and we described the main properties of the Asymmetry Recovering Parser. We illustrated how the parser recovers argument structures and adjunct structures, as well as covert and displaced constituents. In the next section, we provide evidence that deterministic asymmetry recovering parsing can be used for the recovery of adjunct antecedents to impersonal pronouns, such as the pronoun *it* in English. We limit the discussion to the recovery of spatial and temporal antecedents of impersonal pronouns.

3. Discourse pronominal anaphora resolution extended to adjuncts

In this section, we first consider pronominal anaphora to argument positions, and then we discuss anaphora to adjunct positions.

3.1 Pronominal anaphora to argument positions

According to Condition B of the Binding Theory [17], (10), a pronoun must be free in its local domain, such as the domain of the sentence (TP) where it occurs. The binding relation is subject to the asymmetric c-command relation, (10b).

(10) a. *Binding Theory*

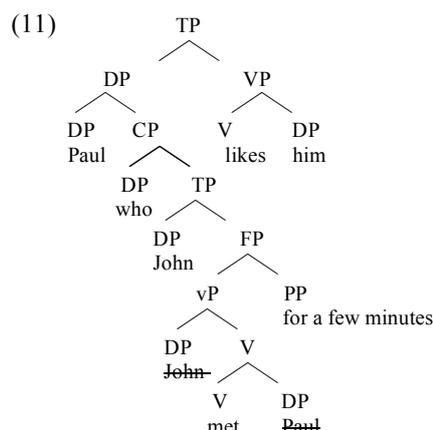
Principle A: An anaphor is bound in its local domain.

Principle B: A pronominal is free in its local domain.

Principle C: An R-expression is free.

- b. x is bound by y : x asymmetrically c-commands y , and x and y are co-indexed.

Consequently, an antecedent that does not asymmetrically c-command a pronoun may serve as a possible antecedent for that pronoun. This is the case when the antecedent is part of a relative clause, as in (11), where *John* is a possible antecedent for the pronoun *him*. In such cases, co-reference and not binding is at stake.



Furthermore, pronouns can be related by co-reference to antecedents in the domain of the discourse. In fact, a pronoun, that is, a constituent lacking independent reference (Ir), must have an antecedent with independent reference, as it is the case for nominal expressions (DP). We will thus assume the interface condition on pronominal anaphora in (12), formulated in [14] in terms of the *Link* operation, which applies only under featural *Agree*. In Asymmetry Theory, pronominal anaphora resolution is essentially the identification of the nominal constituent (DP) with respect to which the features of a pronoun (DPro) stand in a proper inclusion relation.

- (12) *DD-Linking (Discourse Domain-Linking)*
 A pronominal must be linked in its Domain of Discourse.

It has been shown in [13] that asymmetry-based parsing enables the recovery of the antecedents of pronouns, when the antecedent occupies an argument position, as it is the case in the example in (13) and (14). Furthermore, we argued in [23] that deep parsing, instead of shallow or probabilistic parsing, is necessary for Pronominal Anaphora Resolution, to handle cases where the argument is covert, which is expressed in terms of an empty pronominal (PRO, empty pronominal in the position of the subject of an infinitival clause, or Pro, empty pronominal in the object position), (14a), (14b).

- (13) a. The shareholders reinvested in the company. They were looking forward to increase their benefits.
 b. The shareholders reinvested in the company. It had been doing well lately.
- (14) a. The shareholders reinvested in the company. They wanted PRO to invest before the company would be sold.
 b. The shareholders reinvested pro in the company. It was quite an amount.

The formal and semantic features in (15) are necessary for pronominal anaphora resolution based on asymmetric agreement, [13].

(15) *DPros, QPs, and DPs formal and semantic features*

	Form: pers, num, gen	Sem: Ir, ani, w, gr
DPro	+ + +	- +/- +/- +/-
QP	3 rd + u	+ +/- - +/-
DP	3 rd + +	+ +/- +/- +/-

The feature specifications are provided for pronouns (DPros), quantifiers (QPs), and nominal phrases (DPs). They differ with respect to the formal phi-features specifications, including person (pers.), number (num.), and gender (gen.). QPs like DPs are 3rd pers, whereas this is not necessarily the case for DPros. QPs are specified for number features, but not for gender features in languages such as English (this is not the case in some other languages, including the Romance languages). The semantic features include the independent reference feature ([±Ir]), along with the animate ([±ani]) feature, the part-whole ([±w]) feature, and the group ([±gr]) feature. The [±ani] feature differentiates *he* from *it*, and the [±w] feature differentiates anaphoric pronouns, such as *himself*, from non-anaphoric pronouns, such as *he* and *him*, and from DPs. Non-anaphoric pronouns and DPs are [+w], anaphoric pronouns are [-w]. The [±gr] feature differentiates QPs with a group reading, such as *everyone*, from those that do

not have a group reading, such as *someone*.

When applied in the domain of the discourse, the Asymmetry Recovering Parser parses one sentence at the time. For every two sentences parsed it identifies the occurrences of DPros and DPs and selects the set pair consisting of possible DP antecedents and pronouns, the sets of features of which are in a proper inclusion relation. The following examples illustrate the inter-sentential identification of the antecedent of DPros. In each case, there is only one DP in the preceding clause whose features is a superset of the feature of the DPro in the subsequent sentence.

(16) a. [The shareholders reinvested in [the company. [They were looking forward...

$[D, 3^{rd}, pl, +Ir, +ani]$ $[D, 3^{rd}, -pl, +Ir, -ani]$. $[D, 3^{rd}, pl, -Ir, +ani]$

↑

b. [The shareholders reinvested in [the company. [It had been doing well ...

$[D, 3^{rd}, pl, +Ir, +ani]$ $[D, 3^{rd}, -pl, +Ir, -ani]$. $[D, 3^{rd}, -pl, -Ir, -ani]$

↑

(17) a. [The shareholders reinvested in [the company. [They wanted [PRO to invest ...

$[D, 3^{rd}, pl, +Ir, +ani]$ $[D, 3^{rd}, -pl, +Ir, -ani]$. $[D, 3^{rd}, pl, -Ir, +ani]$

↑

b. The shareholders reinvested pro in the company. It was quite ...

$[D, pl, 3^{rd}, +Ir, +ani]$ $[D, pl, 3^{rd}, +Ir, -ani, +arb, \emptyset]$ $[D, 3^{rd}, -pl, +Ir, -ani]$. $[D, 3^{rd}, -pl, -Ir, -ani, +arb]$

↑

3.2 Pronominal anaphora to adjunct positions

We now consider adjunct antecedents to non-expletive uses of pronouns such as *it* and *there*. Before doing so, it is worth noting that there are differences between the expletive, (18) and (20) and the non-expletive, (19), use of *it/there*. One difference is that an expletive pronoun cannot be stressed as opposed to the non-expletive usage of this pronoun. Another difference is that an expletive pronoun has an associated constituent, such as a CP, (18b), whereas this is not the case for the non-expletive use of these pronouns, (19). Yet another difference is that the position of an expletive can be the locus of a displaced argument, (20), whereas this is not the case for a non-expletive.

(18) a. There is a shareholder in the building.

b. It is true that a shareholder is in the building.

(19) a. It is interesting.

b. Lets talk about it.

- (20) a. It seems that a shareholder is in the building.
 b. A shareholder seems to be in the building.

Let us now turn to cases such as (21)-(22) where an adjunct may co-refer with a non-expletive use of the pronoun *it*. The co-reference can be sentence bound, as in (21), where the antecedent of the pronoun is in a relative clause, or it can be as in (22), where the antecedent of the pronoun is in the preceding clause. Thus, non-asymmetrically c-commanded adjuncts can serve as antecedents of pronouns within the domain of the sentence, as well as inter-sententially.

- (21) a. The shareholder that John met on Monday thought that it was a good day for a meeting.
 b. The shareholder that John met in Miami thought that it was a good place for a meeting.
- (22) a. The shareholders reinvested in the company on Monday. It turned out to be a good day for financial transactions.
 b. The shareholders reinvested in the company in Miami. It is now the headquarters of the company.

In order to extend the asymmetry based pronominal anaphora resolution to spatial and temporal adjuncts, the semantic features Space (sp) and Time (ti) are added to the set of semantic features.

(23) *DPros, QPs, and DPs formal and semantic features*

	Form: pers, num, gen, \emptyset	Sem: Ir, ani, w, gr, sp, ti
DPRO/Pro	+ + + +	- +/- +/- +/- +/- +/-
QP	3 rd + u -	+ +/- - +/- +/- +/-
DP	3 rd + + -	+ +/- +/- +/- +/- +/-

The pronominal anaphora system based on asymmetric agreement properly identifies the adjuncts *on Monday* and *in Miami* in the first sentence, as the only possible antecedents for the pronoun *it* in the following sentence. The asymmetric agreement relation between the antecedent adjunct and the pronoun does not hold under asymmetric c-command, but only under Agree, (9). Interestingly, the non-expletive pronoun *it* may co-refer with an adjunct in the domain of the discourse, if it asymmetrically agrees with a DP in its local domain. Without the local agreement, the co-reference does not hold between the adjunct and the pronoun. It holds however between the whole proposition and the pronoun. The following examples illustrate this point. (24a) and (25a), are cases of VP anaphora, where the pronoun co-refers with the VP in the preceding clause. In (24b) and (25b), the pronoun co-refers to an adjunct according to the properties of the covert DP in the local domain of the pronoun, that is in the sentence containing the pronoun.

- (24) a. The shareholders reinvested in the company on Monday. It was good that they did.
 b. The shareholders reinvested in the company on Monday. It was *a good time* to do so.

- (25) a. The shareholders reinvested in the company in Miami. It was good that they did.
 b. The shareholders reinvested in the company in Miami. It was a *good place* to do so.

The proper subset relation must hold between the adjunct in an antecedent clause and a pronoun in a subsequent clause, as expressed in the following representations.

- (26) a. On Monday, the shareholders reinvested in the company. It was a good time ...
- | | | | | |
|--|--|------------------------------------|--|--|
| | | | | |
| [D, +Ir, +3 rd , -ani +ti] | | [D, -Ir, +3 rd , -ani] | | [D, +Ir, +3 rd , -ani, +ti] |
| | | | | |
| | | ↑ | | |

- b. In Miami, the shareholders reinvested in the company. It was a good place ...
- | | | | | |
|--|--|------------------------------------|--|--|
| | | | | |
| [D, +Ir, +3 rd , -ani +sp] | | [D, -Ir, +3 rd , -ani] | | [D, +Ir, +3 rd , -ani, +sp] |
| | | | | |
| | | ↑ | | |

The recovery of the adjunct antecedent of a pronoun is deterministic. It proceeds from left to right and does not backtrack to modify the co-reference relations. Thus in (26a) co-reference between the temporal adjunct in the first sentence and the pronoun in the second sentence holds under feature inclusion: *Monday* is [D, +Ir, +3rd, -ani +ti] and the pronoun *it* is [D, -Ir, +3rd, -ani]; in the domain of the second clause, *time* [D, +Ir, +3rd, -ani, +ti] is the superset and the pronoun *it* is the subset. The same relations hold in (26b) with a locative adjunct as the antecedent of the pronoun. These facts show that adjuncts may serve as antecedent to non-expletive impersonal pronouns in the domain of the discourse if there is a constituent in the local domain of the pronoun whose set of features properly includes the set of features of that pronoun.

- (27) [TP Adjunct [CP [TP DPro DP]]
- | | | | | |
|----------|--|--------|--|----------|
| | | | | |
| Superset | | Subset | | Superset |
| | | | | |

Given the co-reference chain in (27), the antecedent of non-expletive pronouns can be identified deterministically. In the examples in (26a), *Monday* is the only possible antecedent of the non-expletive pronoun, and in (26b) *Miami* is.

To summarize, we extended our asymmetry based pronominal anaphora resolution system to cover adjuncts by minimally extending the set of features to which the *Link* operation may apply. By modifying minimally the set of lexical features, without

modifying the core operations of the grammar and the parser and the locality of their operations/actions, it has been possible to extend the empirical coverage of our system, and improve its accuracy.

4. Discussion and further research

In this paper, we provided empirical evidence that asymmetric relations, couched in terms of agreement between antecedents and pronouns, must be recovered in order to determine the constituents that can be the antecedents of pronouns in the domain of the discourse.

The linguistic operations applying under featural *Agree* identify the antecedents of pronouns whether the antecedent is an argument or an adjunct, whether it is located in the domain of the sentence, or whether the co-reference relation holds across sentences. We proposed to extend the set of features for pronominal anaphora resolution in order to cover the cases where the antecedent does not asymmetrically c-command the pronoun. Given the Asymmetry Theory, *Agree* holds only between sets of features in such cases.

We already showed that our system outperformed the recovery of DP arguments, as antecedent for pronouns by so-called knowledge poor systems, such as MARS, which are not based on the recovery of configurational (asymmetric c-command) or featural relations (proper subset relation). We leave for further research a comparison of the results coming from our system on the recovery of PP adjunct antecedents for pronouns and knowledge-poor approaches, which do not rely on asymmetric *Agree* and deterministic parsing.

We also leave for further work the connection between the system we proposed for recovering pronominal anaphora based on *Agree*, as implemented in the Asymmetry Recovering Parser, and software methods satisfying engineering requirements, such as the method developed in [32]. Such engineering requirements would ensure consistency in the software development process, where each design decision would be a rational consequence of the design decisions taken at earlier steps of the design.

5. Conclusion

We conclude by pointing out the importance of efficient pronominal anaphora resolution systems for Information technologies and Natural language processing more generally. The identification of the reference of pronouns must be part of efficient Information Extraction systems, as pronouns lack independent reference, their reference must be identified by an antecedent with independent reference, whether the antecedent denotes a participant of an event or a situation, whether it denotes the time or the place of an event or a situation. The deterministic recovery of the antecedents of pronouns is also part of efficient Natural Language Processing technologies, whether they seek to provide relevant answers to questions, to extract relevant entities and relations between entities, or to perform automatic reasoning in a domain of interpretation.

Pronouns are commonly used in linguistic expressions, and their processing by humans is fast and efficient. Efficient pronominal anaphora resolution should be part of Information Technologies. Natural Language Processing systems, including data mining, question answering and inference engines, based on a parser recovering asymmetric relations, including asymmetric *Agree*, are likely to be more efficient, since they rely on universal properties of natural language. Information Technologies recovering these relations help to bring Natural Language Processing closer to human performance, as also discussed in [33], [34], [35] [36].

6. Acknowledgements

This work is supported in part by a grant from the SSHRC of Canada to the MCRI on Interface Asymmetries 214-2003-1003, www.interfaceasymmetry.uqam.ca, and by a grant from FQRSC to the Dynamic Interface project 2011-SE-137253, both awarded to Professor Anna Maria Di Sciullo at Université du Québec à Montréal.

References

- [1] R. Kayne. *The Antisymmetry of Syntax*. Cambridge, Mass.: The MIT Press, 1994.
- [2] J. C.-T. Huang. Logical relations in Chinese and the theory of grammar. Ph.D. Dissertation, MIT, 1982.
- [3] J. Nunes. Linearization of Chains and Sideward Movement. Cambridge, Mass.: The MIT Press, 2004.
- [4] J. Nunes & J. Uriagereka. Cyclicity and extraction domains. *Syntax* **3** (2000), 20-43.
- [5] J. Uriagereka. Multiple Spell-out. In *Working minimalism*, ed. Norbert Hornstein & Samuel D. Epstein, 251-282. Cambridge, Mass.: The MIT Press, 1999.
- [6] A.M. Di Sciullo & D. Isac. Movement chains at the interfaces. *Canadian Journal of Linguistics* **53**. (2008), 1001-1037.
- [7] E. Agirre, T. Baldwin & D. Martinez. Improving Parsing and PP attachment Performance with Sense Information. *Proceedings of ACL-2008* (2008), 317-325.
- [8] S. Kubler, S. Ivanova & E. Klett. Combining dependency parsing with PP attachment. *Fourth Midwest Computational Linguistics*. 2007.
- [9] E. Boland & A. Blodgett. Argument status and PP attachment. *Journal of Psycholinguistic Research* **35** (2006), 385-403.
- [10] C. Clifton, S. Speer & S. Abney. Parsing arguments: Phrase structure and argument structure as determinants of initial parsing decisions. *Journal of Memory and Language* **30**(1999), 251-271.
- [11] A.M. Di Sciullo. Parsing asymmetries. *Natural Language Processing- NLP2000. Lecture Notes in Computer Science* **1835** (2000), 24-39.
- [12] A.M. Di Sciullo. *Asymmetry in Morphology*. Cambridge, Mass.: The MIT Press, 2005.
- [13] A.M. Di Sciullo. Domains of Argument Structure Asymmetries. *Proceedings of the 9th World Multiconference on Systemics, Cybernetics and Informatics* (2005), 316-320, 2005.
- [14] A.M. Di Sciullo. Pronominal anaphora processing. *Word Academy of Science, Engineering and Technology II* (2005), 245-259.
- [15] G. Barton, R. Berwick & E. Ristad. *Computational Complexity and Natural Language*. Cambridge, Mass.: The MIT Press, 1987.
- [16] R. Berwick, S. Abney & C. Tenny (eds.). *Principle-Based Parsing*. Dordrecht, Kluwer Academic Publishers, 1991.
- [17] N. Chomsky. *Lectures on Government and Binding*. Dordrecht, Foris, 1981.
- [18] S. Fong. Computational Properties of Principle-Based Grammatical Theories. Ph.D. Thesis, Artificial Intelligence Laboratory, MIT, 1991.

- [19] A.M. Di Sciullo & S. Fong. Efficient parsing for word structure. *Proceedings of the 6th Natural Language Processing Pacific Rim Symposium (2001)*: 741-748.
- [20] A.M. Di Sciullo & S. Fong. Asymmetry, Zero Morphology and Tractability. *Language, Information and Computation. PACLIC 15* (2002), 61-72.
- [21] A.M. Di Sciullo & S. Fong. Morpho-Syntax Parsing. In *UG and External Systems*, ed. A.M. Di Sciullo, 247-268, Amsterdam/Philadelphia: John Benjamins, 2005.
- [22] A.M. Di Sciullo, P. Gabrini, C. Batori, & S. Somesfalean. "Asymmetry, the grammar, and the parser", *Linguistica e modelli tecnologici di ricerca. Atti del XL Congresso Internazionale di Studi della Società Linguistica Italiana*, 477-494, Monica Mosca, Bulzoni, 2010.
- [23] A.M. Di Sciullo, S. Somesfalean, C. Batori, & P. Gabrini. Pronominal Anaphora Understanding. *Intelligent systems Design and Applications (ISDA)* (2010), 1107-1112.
- [24] D. E. Knuth. On the Translation of Languages from Left to Right, *Information and Control* **8** (1965): 607-639.
- [25] J. Earley. An efficient context-free parsing algorithm. *Communications of the Association for Computing Machinery* **13** (1970), 94-102, 1970.
- [26] M. Wirén. Interactive incremental chart parsing. *Proceedings of the Fourth Conference of the European Chapter of the Association for Computational Linguistics* (1989), 241-248.
- [27] M. Wirén. Bounded incremental chart parsing. Clause Report 36 (1994), Universität des Saarlandes, Saarbruucken, Germany.
- [28] M. Marcus. A Theory of Syntactic Recognition for Natural Language. Cambridge, Mass.: The MIT Press, 1980.
- [29] H. Thompson. Mchart: A flexible, modular chart parsing system. *Proceedings of the Third National Conference on Artificial Intelligence*. Washington, 1983.
- [30] S. Fong. Computation with probes and goals. In *UG and External Systems: Language, Brain and Computation*, ed. A.M. Di Sciullo, 311-334, Amsterdam/Philadelphia: John Benjamins, 2005.
- [31] H. Harkema. Minimalist languages and the correct prefix property. In *UG and External Systems. Language, Brain and Computation*, ed. A.M. Di Sciullo, 289-310, Amsterdam/Philadelphia: John Benjamins, 2005.
- [32] D. Parnas. Document based rational software development. In *Knowledge-Based Systems* **22** (2009), 132-141.
- [33] A.M. Di Sciullo. An integrated competence-performance model, a prototype for Morpho-Conceptual Parsing and consequences for information processing, *Proceedings of VEXTAL*, 369-379, University Ca'Foscari, Venice, 1999.
- [34] A.M. Di Sciullo & C. Agüero Bautista. Natural language asymmetries and the construction of Question Answering Systems, In *Proceedings of the 7th Multiconference on Systemics, Cybernetics, and Informatics. Vol. 1. Information Systems. Technologies and Applications*, ed. N. Callaos, A.M. Di Sciullo, T. Ohta & T.-K. Liu (eds.), 13-18, Orlando, 2003.
- [35] A.M. Di Sciullo. Natural Language Asymmetry in Internet Infrastructure. *International Journal of E-Business* **3** (2005), 328-238.
- [36] A.M. Di Sciullo. Information processing. In *New Trends in Software Methodologies Tools and Techniques. Frontiers in Artificial Intelligence and Applications*, ed. H. Fujita & D. Pisanelli, 437-456, Amsterdam: IOS Press, 2010.