Meta-level constraints for representing interaction between linguistic domains

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Abstract

This paper presents a technique for the representation and the implementation of interaction relations between different domains of linguistic analysis. This solution relies on the localization of the linguistic objects in the context. The relations are then implemented by means of interaction constraints, each domain information being expressed independently.

1 Introduction

Descriptive linguistics as well as natural language processing are faced with the question of integrating different sources of information, coming from different domains of linguistic analysis such as prosody, phonology, syntax, discourse, semantics, etc. None of these domains can be treated independently. More precisely, the interaction between domains contains in itself many information that is not accessible directly. It is then necessary to explain how such interaction is possible. Unfortunately, even if many works exist describing the interface between two of these domains (e.g. prosody/syntax interaction), none of them provide a general framework for (1) representing and (2) implementing such interaction. Both questions are equally important. Indeed, we think that the main obstacles of the classical approaches come from the fact that relations between domains are classically expressed between high-level structures (e.g. a syntactic tree and a prosodic hierarchy) and that these approaches (typically the generative ones in syntax) cannot easily deal with partial, spread or even ill-formed information.

We propose in this paper some elements of answer for these problems in which the representation level relies on an *anchoring* system allowing to localize any kind of information at any level. The interaction itself can then be implemented directly by means of *interaction constraints*. In a fully constraint-based approach as the one proposed here, interaction constraints exploit the interpretation of the state of the constraint system for each domain in order to propagate new information: they constitute then a meta-level. This method presents several interests. First, it constitutes an efficient tool for controlling the parse of the different domains and implements directly some disambiguation information (see section 4). But it also represents a first step towards a general account of a multi-perspective linguistic analysis in which information is spread into the different domains. In this approach, interpretation relies first on partial information coming from these domains and second on the interaction between them.

2 Domain interaction

The question of the interaction between different components of linguistic analysis is generally addressed in terms of relations between structures. In this perspective, it becomes very difficult to consider more than two structures at the same time and this probably explains that existing works usually take into consideration only two components (prosody/syntax, syntax/semantics, etc.). Such approaches presents several problems. One is the necessity of representing information and rules within a unique formalism: relations depend in this case on the way of representing information. Moreover, we need for this a very specific architecture consisting in building first the respective structures, analyzing them, and applying finally some interaction rules expressed in terms of correspondence relations between these structures. We think that one of the problems comes from the choice of the interaction level between the components. It seems preferable to use a low-level anchoring system that makes it possible to localize the information in the input. It becomes then possible to represent information over a given segment of the input instead of a structure. In this perspective, relations between domains are independent from any formalism and rely on the characterization of some properties from each domain.

We present in the following some interaction examples between different domains. [Bear90] proposes an implementation of the interaction between prosodic breaks and syntactic constituents. The authors observe that when a large prosodic break appears between two words, they do not combine to form a constituent in which the corresponding categories are sisters. In other words, no major prosodic break can separate a lexical head and a juxtaposed complement whereas rather long breaks can appear between two complements. This kind of information is of great help during a parse and allows to resolve many ambiguous attachments. The authors represent this information directly in the grammar by inserting a new category, called *Link*, between each category of a right-hand side of a phrase structure rule. Each *Link* can be constrained in its possible values. For example, in the rule $VP \rightarrow V\ Link\ PP$, the break between V and PP cannot be greater than 2 (in a scale of 0-5). It follows from this integrative representation two possibilities. Either we think possible and necessary to represent a full prosodic description containing other information than breaks (such as tone, accent, duration, etc.). In this case, the insertion of prosodic information into PS-rules requires a complete superposition of prosodic and syntactic structures. The second possible choice consists in considering breaks as syntactic categories. In our opinion, these interpretation are equally bad.

Another example of prosody/syntax interaction is given in [Hirst93]. The author proposes a rule predicting the possible intonational phrases from a syntactic tree. This rule is formulated as follows: "*Detach a constituent [X] recursively and optionally from the right edge of a syntactic tree, where [X] is a major category (S, NP, VP or PP)*". In the case of the tree: $[_S\ [_{NP}$ Jane$]$ $[_{VP}\ [_V$ gave$]$ $[_{NP}$ the book$]$ $[_{PP}$ to$[_{NP}$ Mary$]]]]$ the rule predicts the following phrasings:

1.	(Jane gave the book to Mary)	4.	(Jane)(gave the book)(to Mary)
2.	(Jane gave)(the book to Mary)	5.	(Jane)(gave)(the book)(to Mary)
3.	(Jane gave the book)(to Mary)	6.	(Jane gave)(the book)(to Mary)

This kind of rule is also highly dependent from the structure and more generally the formalism. In this case, the information is not integrated to the grammar as in the previous example, the rule is situated at a higher level which gives some kind of priority to the syntactic structure which has to be built before rule application.

The third example illustrates a less studied interaction between graphics and texts. [Pineda00] proposes a description of coreferences between objects from different domains. The problem consists in associating a text and a map. Several objects are described in both sources, the question is to find the coreferent ones. This consists for example in associating a point with a city, a line with a border, etc. then to resolve the reference by means of information coming from one domain or another. For example, let's imagine a line between two points and a text telling that *Paris* is to the west from *Berlin*. Then, it becomes possible to associate them respectively to the right and the left point. [Pineda00] proposes a multimodal version of DRT (see [Kamp93]) in which all possible referents (for each domain) are indicated together with properties plus an interaction level specifying some *translation* constraints between the domains. In this case, each domain keeps in a certain sense its autonomy, the interaction is represented by the fact that there is a common set of objects plus some equations unifying them. This technique relies on the fact that both domains gives information over semantic objects whereas in the previous examples, information was given over objects located at the same position in the signal. However, as in the previous cases, interaction is described in terms of superposition: it is implemented by means of translation between the language of one domain towards the language of the other.

These examples illustrate several problems. It is clear that the different linguistic domains interact. But this can only exceptionally be described in terms of structure superposition (as for morphology/phonology interaction as described in [Bird94]). Usually, there is a certain kind of correspondence between subparts of domain information, as described in [Hirst93]. But it seems difficult, or even impossible, to systematize such an approach in order to implement all the possible domain interactions.

3 Anchoring the different levels

An important part of the problem consists in finding an interface point between domains more than an alignment between structures. As it is the case in multimodal communication, several parameters have to be taken into account, in particular redundancy and synchronicity.

In some cases, information is synchronous, for example between prosody and gestures (see [Kettebekov02]). In some other cases, it is asynchronous but redundant in the sense that it refers to the same interpretation domain. In both cases, there exists a common point making it possible to indicate that two sets of properties refer to the same object.

We propose to specify a new kind of feature describing a position (or more generally a localization) that can be associated to an information. This idea to refer to the information by means of its localization is experimented in corpus annotation works (see [Bird01] or [Blache01a]). We propose here to define a generic solution for indexing any kind of information. For some domains (typically prosody) a temporal indexing comes naturally in mind. But, as shown before, it is not adequate for all domains. A linear indexing over the string is for example necessary for indexing written material. Finally, we also need to index information that is not usually associated with a given position but more generally with a context. This is typically the case for discourse information. We propose then to use an anchor which is represented by a complex feature as follows:

$$\text{ANCHOR} \begin{bmatrix} \text{TEMPORAL} \ \langle i,\ j \rangle \\ \text{POSITION} \ \langle k,\ l \rangle \\ \text{CONTEXT} \ c \end{bmatrix}$$

The temporal index is represented by two values (beginning and end). The position is also a couple of indexes (corresponding to nodes in a chart interpretation) localizing an object in the input. The CONTEXT feature implements the notion of *universe* (i.e. a set of discourse referents) as in DRT. An object can then be specified by means of different kind of information: its *domain* and its *characterization* (the set of corresponding properties) containing its *anchor*. The following example describes an object from the syntactic domain, with a precise localization both on the temporal and the linear axis:

$$\text{OBJ} \begin{bmatrix} \text{DOMAIN} \ \mathit{synt} \\ \text{CHARAC} \begin{bmatrix} \text{CAT} \ \mathit{Det} \\ \text{ANCHOR} \begin{bmatrix} \text{TEMP} \ \langle 880,\ 1000 \rangle \\ \text{POSITION} \ \langle 2,\ 3 \rangle \end{bmatrix} \end{bmatrix} \end{bmatrix}$$

4 Meta-level constraints

Representing interaction between different linguistic domains requires the possibility of representing direct relations between the objects of these domains. But this is not sufficient and in most of the cases, such interaction relations require the knowledge of more information, in particular the local relations that can exists between objects (e.g. function in syntax). This kind of multi-level information is easily accessible when using a constraint-based approach in which all information, at any level, is represented by means of constraints (also conceived as properties). We describe here such an approach, called *Property Grammars*, and show how it can deal with different levels of constraint.

4.1 Representing information by means of constraints

We present in this section the formalism of *Property Grammars* (see [Blache00]), in which all information is represented my means of constraints. Concerning syntax, the following set of constraints can be used: *linearity, dependency, obligation, exclusion, requirement* and *uniqueness*[1]. They can be presented as follows:

Constraint	Definition	Example
Linearity ($\prec$)	Linear precedence constraints.	$Det \prec N$
Dependency ($\leadsto$)	Dependency relations between categories.	$AP \leadsto N$
Obligation ($\mapsto$)	Set of compulsory and unique categories. One of these categories (and only one) has to be realized in a phrase.	$N \mapsto NP$
Exclusion ($\not\Leftrightarrow$)	Restriction of cooccurrence between sets of categories.	$N[pro] \not\Leftrightarrow Det$
Requirement ($\Rightarrow$)	Mandatory cooccurrence between sets of categories.	$N[com] \Rightarrow Det$
Uniqueness (*Uniq*)	Set of categories which cannot be repeated in a phrase.	$Uniq(NP) = \{Det, N, AP, PP, Pro\}$

Each category is described in the grammar with a set of such constraints. A grammar corresponds then to a constraint system. In this approach, analyzing an input comes to evaluate the constraint system. The state of the system after evaluation contains for each category the set of constraints together with their status (satisfied or not). This result (called *characterization*) contains all the necessary information (actually more than a classical syntactic structure) in order to specify precisely the syntactic properties of the input.

In this approach, the general parsing mechanism (see [Blache01b]) consists, starting from the set of lexical categories, in identifying all the relations connecting the categories. As a side effect, this process can instantiate new feature values as well as new categories. The following schema presents the core of the process. It consists in evaluating for all subsets of categories whether they can be evaluated with respect to the constraint system. If so, the set of evaluated constraints is added to the characterization of the corresponding category X. This characterization is to its turn added to the constraint store of the domain and the new category X is added to the set of categories.

```
S = set of categories
for each S' ⊂ S
    SAT(S') ⇝ X
    if X≠ ∅
        Charac(X) ← SAT(S')
        Store(X) ← Charac(X)
        S ← S ∪ {X}
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At the end of the process, we obtain a set of categories together with their characterization. It is then possible to exhibit one (or several) solutions which correspond to a total coverage of the input. It is important to notice that a characterization can contain non-satisfied constraints, which means that it is possible to characterize any kind of input, being it grammatical or not.

[1] It can be the case that other kind of constraints are necessary (e.g. the juxtaposition relation). One simply have to add the required constraint to the system without modifying the general architecture.

This constitutes obviously an important difference with other approaches.

4.2 A meta-level for the description of interaction

The description of domain interaction takes advantage of the constraint-based approach presented above. The idea is to propose a mechanism making it possible to infer new properties according to the different characterizations produced for different domains. In other words, this new kind of constraint specifies a relation between characterizations (rather than between categories). Insofar as different sources of information, coming from different domains, are involved in these relations, the characterizations have to specify the domain and the anchor. A first approximation of the interaction relation can be represented as follows:

(1)
$$\left\{ \text{OBJ}_i \begin{bmatrix} \text{DOMAIN } d_i \\ \begin{bmatrix} \text{CHARAC } c_i \\ \text{ANCHOR } a_i \end{bmatrix} \end{bmatrix}, \ldots, \text{OBJ}_j \begin{bmatrix} \text{DOMAIN } d_j \\ \begin{bmatrix} \text{CHARAC } c_j \\ \text{ANCHOR } a_j \end{bmatrix} \end{bmatrix} \right\} \Rightarrow \left\{ \text{OBJ}_k \begin{bmatrix} \text{DOMAIN } d_k \\ \begin{bmatrix} \text{CHARAC } c_k \\ \text{ANCHOR } a_k \end{bmatrix} \end{bmatrix}, \ldots, \text{OBJ}_l \begin{bmatrix} \text{DOMAIN } d_l \\ \begin{bmatrix} \text{CHARAC } c_l \\ \text{ANCHOR } a_l \end{bmatrix} \end{bmatrix} \right\}$$

Such a relation means that when the different characterizations $\{\text{OBJ}_i, \ldots \text{OBJ}_j\}$, eventually coming from different domains, are exhibited, then the new properties stipulated in the characterizations $\{\text{OBJ}_k, \ldots \text{OBJ}_l\}$ are added to the general description. Moreover, it is possible (even necessary) to specify a kind of meeting point between the domains indicating that the different characterizations specify the same phenomenon. This is done by means of the ANCHOR feature. Two kind of relations can be used in such interaction constraints: an inference one, similar to the *requirement* relation in property grammars, and an exclusion one stipulating a cooccurrency restriction between two characterizations. The general schema consists now in building characterizations of each domain and propagating new properties according to the interaction constraints. This propagation is done at the same time as the satisfaction process: new properties are propagated thanks to interaction as soon as the corresponding characterizations are instantiated. The evaluation of the interaction constraint constitutes in itself a part of a general characterization of the input. It establishes then some relations (requirement or exclusion) between categories that can have a disambiguation effect.

We illustrate in the following this aspect with an example of interaction constraints implementing the relation described in [Bear90] and presented in the first section. It stipulates that no major breaks can separate two juxtaposed sisters connected with a complementation relation (represented by $\leadsto$). The anchoring information allows to situate each object. This is the main interest of such a representation: an object only have to be located, its properties can be expressed independently by means of any formalism.

(2)
$$\begin{bmatrix} \text{DOM} & \textit{synt} \\ \text{CHAR} & \begin{bmatrix} \begin{bmatrix} \text{CAT} & c_1 \\ \text{ANCH} & \begin{bmatrix} \text{TEMP} & \langle t_1,\ t_2 \rangle \\ \text{POS} & \langle i,\ j \rangle \end{bmatrix} \end{bmatrix} \\ \begin{bmatrix} \text{CAT} & c_2 \\ \text{ANCH} & \begin{bmatrix} \text{TEMP} & \langle t_3,\ t_4 \rangle \\ \text{POS} & \langle k,\ l \rangle \end{bmatrix} \end{bmatrix} \\ \text{DEP}\ c_2 \rightsquigarrow c_1 \end{bmatrix} \end{bmatrix} \not\Leftrightarrow \begin{bmatrix} \text{DOM} & \textit{pros} \\ \text{CHAR} & \begin{bmatrix} \text{CAT} & \textit{break} \\ \text{ANCH} & \begin{bmatrix} \text{TEMP} & \langle t_2,\ t_3 \rangle \\ \text{POS} & \langle j,\ k \rangle \end{bmatrix} \end{bmatrix} \end{bmatrix}$$

This interaction constraint connects two characterizations coming from the prosodic and the syntactic domains. Such interaction constraint typically works for attachment disambiguation. In case of ambiguity (for example in PP attachment), the interpretation that will be favored thanks to this constraint is the one at the higher level when a major break precedes the PP.

5 Perspectives

Interaction constraints can represent many different kind of information. In particular, they can be generalized to the representation of multimodal relations by means of the proposed anchoring system, including temporal and contextual indexes. We present in this section some examples illustrating these aspects.

The first constraint, implement a coreference relation my means of unification. In this case, interaction constraint is represented with a conjunction. It involves three characterizations coming from three different domains.

(3)
$$\begin{bmatrix} \text{DOM} & \textit{gesture} \\ \text{CHAR} & \begin{bmatrix} \textit{deictic} \\ \text{ANCH} & \begin{bmatrix} \text{TEMP} & \langle i,\ j \rangle \\ \text{CONT} & C \end{bmatrix} \end{bmatrix} \end{bmatrix} \wedge \begin{bmatrix} \text{DOM} & \textit{lang} \\ \text{CHAR} & \begin{bmatrix} \text{SEM} & \begin{bmatrix} \text{REF} & x \end{bmatrix} \\ \text{ANCH} & \begin{bmatrix} \text{TEMP} & \langle i,\ j \rangle \end{bmatrix} \end{bmatrix} \end{bmatrix} \wedge \begin{bmatrix} \text{DOM} & \textit{graph} \\ \text{CHAR} & \begin{bmatrix} \text{SEM} & \begin{bmatrix} \text{REF} & x \end{bmatrix} \\ \text{ANCH} & \begin{bmatrix} \text{CONT} & c_1 \in C \end{bmatrix} \end{bmatrix} \end{bmatrix}$$

The constraint (3) represents a relation between gesture, graphics and language domains, occurring for example during weather TV broadcasts. The constraints indicates that a deictic gesture (see [Kettebekov02]), in a certain universe (noted C) at a given time, stipulates a coreference between an object specified in the language domain (for example a pronoun) at the same time position and a discourse referent from the graphical domain (for example a map) that belongs to the universe C. This constraint is formalized as a conjunction (rather than an implication) indicating a covariation, the different object descriptions being at the same level.

(4)
$$\begin{bmatrix} \text{DOM} & \textit{ling} \\ \text{CHAR} & \begin{bmatrix} \text{SEM} & \begin{bmatrix} \text{REF} & x \\ \text{CONTENT} & \begin{bmatrix} \text{QUANT} & \exists x \\ \text{REL} & \textit{weaken(x)} \end{bmatrix} \end{bmatrix} \\ \text{ANCHOR} & \begin{bmatrix} \text{CONTEXT} & c_1 \end{bmatrix} \end{bmatrix} \end{bmatrix} \wedge \begin{bmatrix} \text{DOM} & \textit{graphics} \\ \text{CHAR} & \begin{bmatrix} \text{SEM} & \begin{bmatrix} \text{REF} & y \\ \text{CONTENT} & \begin{bmatrix} \text{QUANT} & \exists y \\ \text{REL} & \textit{storm(x)} \end{bmatrix} \end{bmatrix} \\ \text{ANCHOR} & \begin{bmatrix} \text{CONTEXT} & c_1 \end{bmatrix} \end{bmatrix} \end{bmatrix} \Rightarrow$$

$$\left[\text{CHAR}\left[\begin{array}{l}\text{SEM}\left[\begin{array}{l}\text{REF } x\\ \text{CONTENT}\left[\begin{array}{l}\text{QUANT } \exists x\\ \text{REL } storm(x) \wedge weak(x)\end{array}\right]\end{array}\right]\\ \text{ANCHOR}\left[\text{CONTEXT } c_1\right]\end{array}\right]\right]$$

The example (4) presents a (simplified) result of the application of the previous constraint. It describes the situation of a pointing gesture (not represented here) towards the picture of a *storm* on a map while producing the sentence "*this one weakens*". The result is the unification of the different properties coming from coreference.

6 Conclusion

We have presented in this paper a technique making it possible to refer to any kind of information by means of a complex anchor feature. The possibility of indexing information on a temporal axis or with respect to a discourse universe allows to represent interaction relation independently from any formalism. Each domain can then be described according to its own representation or theory. Such a representation makes it possible to implement interaction by means of constraints which constitutes a meta-level on top of the grammars or the systems describing each domain. It becomes then possible to express relations involving any kind of information coming from different domains.

References

[Bear90] Bear J. & P. Price (1990), "Prosody, Syntax and Parsing", in proceedings of the *ACL-90*.

[Bird94] Bird S. & E. Klein (1994), *Phonological Analysis in Typed Feature Systems*, Computational Linguistics, 20:3.

[Bird01] Bird S. & M. Liberman (2001) "A formal framework for linguistic annotation", in *Speech Communication*, 33:1.

[Bird00] Bird S. & al. (2000) "ATLAS: A flexible and extensible architecture for linguistic annotation", in proceedings of *LREC-2000*.

[Blache00] Blache P. (2000). "Constraints, Linguistic Theories and Natural Language Processing", in Natural Language Processing, D. Christodoulakis (ed), Lecture Notes in Artificial Intelligence 1835, Springer-Verlag

[Blache01a] Blache P. & D. Hirst (2001) "Aligning Prosody and Syntax in Property Grammars.", in proceedings of *Eurospeech-2001*.

[Blache01b] Blache P. & J.-M. Balfourier (2001). "Property Grammars: a Flexible Constraint-Based Approach to Parsing", in proceedings of *IWPT-2001*.

[Hirst93] Hirst D. (1993), "Detaching Intonational Phrases from Syntactic Structure", in *Linguistic Inquiry*, 24:4.

[Kamp93] Kamp H. & U. Reyle(2002), *From Discourse to Logic*, Kluwer.

[Kettebekov02] Kettebekov S. M. Yeasin & R. Sharma (2002), "Prosody Based Co-analysis for Continuous Recognition of Coverbal Gestures", in proceedings of *International Conference on Multimodal Interfaces*.

[Pineda00] Pineda L. & G. Garza (2000), "A Model for Multimodal Reference Resolution", in Computational Linguistics 26:2.

[Pollard94] Pollard C. & I. Sag (1994), *Head-driven Phrase Structure Grammars*, CSLI, Chicago University Press.