Gradience, Constructions and Constraint Systems

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Abstract. One important question to be addressed by modern linguistics concerns the variability of linguistic constructions. Some of them are very regular, some others quite rare. Some are easy to explain, some others hard. And finally, some are canonical whereas some others are less grammatical. These different aspects have been addressed, usually separately, from a psycholinguistic perspective. Some elements of explanation are given in terms of sentence complexity and gradience (see for example [Gibson00], [Sorace04]). It is necessary to explain why some utterances can be interpretable more easily than some others, or why some are less acceptable than others.

Several linguistic theories address explicitly such questions, in particular from the perspective of dealing with ill-formed inputs. Some elements of answer can be found for example in the *optimality theory* (see [Prince93]), in the *model-theoretic syntax* approach (see [Pullum03]) or in *construction grammar* (see [Fillmore98], [Goldberg95]). One of the main challenges in these approaches, is the characterization of gradience in linguistic data. The basic idea consists in hierarchizing the linguistic information according to some "importance" criterion. However, such importance is difficult to define. In some approaches such as probabilistic grammars, it relies on frequency information (see [Keller03]): each rule is weighted according to its frequency acquired on treebanks. The syntactic constructions are specified according to the weights of the different rules. In some other approaches, explored in this paper, the idea is to propose some objective information relying on a symbolic representation.

This paper argues in favor of a fully constraint-based approach representing all kind of information by means of constraints. Such an approach makes it possible to quantify the information and proposes an ordering relation among the different utterances relying on the interpretation of satisfied and violated constraints.

1 Constructions

Several modern approaches in linguistics argue in favor of a contextual description of linguistic phenomena. This way of representing information is typically proposed in construction grammar (see [Fillmore98] or [Kay99]), in property grammars (see

[Blache00]), etc. In these approaches, a specific phenomenon is characterized by a convergence of different properties. For example, taking into account the syntactic level alone, a dislocated construction is roughly characterized by the realization of an NP, before or after a main clause, together with an anaphoric clitic inside this clause. Other properties can be added to this framework, for example concerning the lexical selection that can be specific to this construction. The important point is that a construction is specified by a given set of properties, some of them being relevant only for this construction. In other words, given the fact that, as proposed in property grammars, a property can be conceived as a constraint, a construction is defined by a constraint system: what makes sense is not a property taken separately from the others, but the interaction of the constraints. Contextuality is then implemented by means of such interaction: defining a construction consists in specifying on one hand a set of properties characterizing the construction and on the other hand some property subset that specifically entails some properties. For example, in the description of passive in French, an accusative pronoun in the VP has to agree with the subject (has to be reflexive).

(1) Je me le suis dit (*I myself it aux-1st tell*)
(2) *Je te le suis dit (*I you it aux-1st tell*)

Such an approach presents several advantages. First, it is possible to express constraints at very different granularity levels for the specification of a given construction. Moreover, different kinds of constraints, coming from different linguistic domains such as prosody, semantics, pragmatics, etc. can participate to the definition of a construction. It is one of the main arguments in favor of construction approaches. This aspect is illustrated in the following example (from [Mertens93]) illustrating a very specific construction in which only a little information is available at the syntactic level. In this case, prosody plays an important role in its interpretation:

(3) lundi lavage mardi repassage mercredi repos
   monday washing tuesday ironing wednesday rest

Finally, a constraint can have in such perspective a relative importance. For some constructions, a constraint can be obligatory whereas the same constraint can be easily relaxed in some other cases.

2 Constraints

Classically, constraints are used in linguistic theories as a filtering process. This is typically the case with constraint grammars, but also with most recent constraint-based approaches such as HPSG (see [Sag99]) or Optimality (see [Prince93]). In HPSG for example, constraints are applied to a structure in order to verify its well-formedness. As a side effect, constraints can also implement feature values instantiation or propagation. The valence principle for example plays exactly this double role: ruling out the structures that don't satisfy the constraint and, in case of unification between a structure and a description in the valence list, instantiating some feature values of the structure. In this case, constraints are seen as structure descriptions, they don't implement information that can be possibly evaluated independently from these structures. This means that structures are first to be built before verifying their values and syntactic properties are expressed in terms of relations inside such hierarchized constructions.

Constraints are used in a completely different way in OT. They also constitute a filtering process, but the constraints belong to a system containing two main pieces of information: the basic information specified by the constraint itself, expressed in universal and imperative terms and a second-level (rather implicit) information expressed by ranking. In such system, the fact that a constraint is satisfied or not is in the end less important than its position in the ranking. Moreover, all constraints are stipulated taking into account the fact that other opposite constraints also belong to the system. This is a kind of negative way of using constraints that are in fact stipulated so as to be violated.

There is a common basis of these different uses of constraints. In all cases, they need to be interpreted into a system. In other words, they cannot be evaluated for themselves, but in reference to the entire system. This is what Pullum underlines as a holistic way of seeing syntactic information in which a syntactic property cannot be interpreted in itself. This is a limitation in the perspective of finding syntactic characterizations of unrestricted material: in many cases, especially when parsing spoken languages, syntactic information is sparse. For example in (3), the relation among the different elements is difficult to express at the syntactic level.

In such cases, information comes from the interaction of different linguistic domains, in particular morphology and prosody more than other kinds of information. And in such cases, classical approaches fail to build a description. There is also another drawback. In the case of OT for example, ranking makes it possible to order different candidates. Such ranking expresses a level of well-formedness, according to the grammar. However, there is no direct relation between well-formedness and more general notions such as understandability, acceptability, sentence complexity, etc. What is important to explain from a cognitive point of view is what kind of utterances are more easily interpretable and why.

We think that constraints can play an important role in this perspective provided that they are expressed in a non holistic manner. In such a perspective, each constraint must implement a syntactic property and be expressed independently from the others. Obviously, constraints have to interact, but they can always be evaluated. This characteristic is underlined by Pullum as being one of the interests of a model-theoretical approach in comparison with a deductive one: it is possible to give some information in all cases, whatever the input form.

2.1 Property Grammars

We briefly describe here a framework for such an approach called *property grammars* (see [Blache00]). In this approach, all information is represented by means of constraints (also called properties). These constraints are relations among categories expressed as a set of features. A category, at the difference with HPSG, doesn't contain hierarchical information among constituents, but only what is called in construction grammar *intrinsic* information. All constraints are expressed independently from the others and represent a specific kind of syntactic information:

- linear precedence, which is an order relation among constituents,
- subcategorization, which indicates the co-occurrence relations among categories or sets of categories,

- the impossibility of co-occurrence between categories,
- the impossibility for a category to be repeated,
- the minimal set of obligatory constituents (usually one single constituent) which is the head,
- the semantic relations among categories, in terms of dependency.

These different kinds of information correspond to different properties, respectively: *linearity, requirement, exclusion, unicity, obligation, dependency*. Such information can always be expressed in terms of relations among categories, as shown in the following examples:

- Linear precedence: *Det* $\prec$ *N* (a determiner precedes the noun)
- Dependency: *AP* $\rightsquigarrow$ *N* (an adjectival phrase depends on the noun)
- Requirement: *V[inf]* $\Rightarrow$ *to* (an infinitive comes with *to*)
- Exclusion: *most* $\not\Leftrightarrow$ *Adj[super]* (*most* can not modify an adjective that already is a superlative.)

Here is a more formal representation of such information :
let $\mathcal{K}$ be a set of categories, $\mathcal{A}$ be the ordered set of categories for a given input,
let $pos(\mathcal{C}, \mathcal{A})$ be a function that returns the position of $\mathcal{C}$ in $\mathcal{A}$,
let $card(\mathcal{C}, \mathcal{A})$ be a function that returns the number of elements of type $\mathcal{C}$ in $\mathcal{A}$,
let $\{\mathcal{C}_1, \mathcal{C}_2\} \in \mathcal{K}$,
let $comp(\mathcal{C}_1, \mathcal{C}_2)$ be a function that verifies the semantic compatibility of $\mathcal{C}_1$ and $\mathcal{C}_2$ and that completes the semantic structure of $\mathcal{C}_2$ with that of $\mathcal{C}_1$[3]

- LP: $\mathcal{C}_1 \prec \mathcal{C}_2$ holds in $\mathcal{A}$ iff $pos(\mathcal{C}_1, \mathcal{A}) < pos(\mathcal{C}_2, \mathcal{A})$
- Req: $\mathcal{C}_1 \Rightarrow \mathcal{C}_2$ holds in $\mathcal{A}$ iff $\mathcal{C}_1 \notin \mathcal{A}$ or $\mathcal{C}_2 \in \mathcal{A}$
- Excl: $\mathcal{C}_1 \not\Leftrightarrow \mathcal{C}_2$ holds in $\mathcal{A}$ iff $\{\mathcal{C}_1, \mathcal{C}_2\} \cap \mathcal{A} \neq \{\mathcal{C}_1, \mathcal{C}_2\}$
- Uniq: $Uniq(\mathcal{C}_1)$ holds in $\mathcal{A}$ iff $card(\mathcal{C}_1, \mathcal{A}) \leq 1$
- Oblig: $Oblig(\mathcal{C}_1)$ holds in $\mathcal{A}$ iff $card(C_1, \mathcal{A}) = 1$
- Dep: $\mathcal{C}_1 \rightsquigarrow \mathcal{C}_2$ holds in $\mathcal{A}$ iff $comp(\mathcal{C}_1, \mathcal{C}_2)$ holds

A grammar is in this perspective a set of constraints, and nothing else. In particular, there is neither ranking in the OT sense nor need of building any structure before being able to evaluate the properties (as in OT with the Gen function or in HPSG with the need of selecting first a hierarchized structure type). Parsing in property grammars consists in evaluating for a given input the entire set of constraints. The characterization of an input is then formed by the set of satisfied constraints and the set of violated ones. More precisely, the grammar contains for each category a subset of constraints. It is then possible to specify for each category as well as for the entire input a characterization (the set of evaluated constraints).

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[3] The semantic completion follows some schemas such as *subject, complement* or *modifier*. These schema indicate what part of the semantic structure of the modified category must be completed with that of the dependent.

## 2.2 Property Grammars and Constraint Solving Problem

Unlike a more standard way of seeing a constraint solving problem which would consist in finding an assignment that satisfies the system of constraints, we start here with a partial assignment—corresponding to the utterance to be parsed—and we want to complete this assignment so as to satisfy the system of constraints—i.e. the grammar. In terms of output of the solving process we are not only interested in the qualitative aspect of the final assignment but equally in knowing which constraints are satisfied and which ones are not, both from a qualitative and a quantitative point of view. The knowledge of the assignment by itself is not enough. Actually, what we want to know is, given a system of constraints and a first partial assignment—representing the input to be analysed— a description of the final system and the complete assignment used to reach it. In a linguistic perspective it means that we want to know the lists of properties which are satisfied and violated by the input utterance—i.e. the characterisation—when the input is analysed in such way—i.e. for a given assignment.

2.3 Constructions and Constraints

A fully constraint-based view such as the one proposed by property grammars makes it possible to implement contextual fine-grained information. In the same way as categories are described by means of constraint subsets, other kind of objects such as constructions can also be specified in the same way. The notion of construction is of deep importance, especially in the perspective of finding gradient judgements: the importance of a constraint can vary from one construction to another. In the remainder of this section, we describe how constructions can be represented by means of constraints in the PG framework, taking the example of the subject-auxiliary inversion (SAI) construction in English (see [Fillmore98]). In this construction, there are strong linear constraints, especially concerning adverbs as shown in the following examples:

(4) Did you learn your lesson?
(5) Did you really learn your lesson?
(6) Didn't you learn your lesson?
(7) *Did really you learn your lesson?
(8) *Did not you learn your lesson?
(9) *Did you your lesson learn?

This construction is explained by the following SAI construction:

inherit VHP
level [srs +]

head $\begin{bmatrix} aux + \\ finite + \end{bmatrix}$ rel [gf subj]   rel [gf ¬subj] *
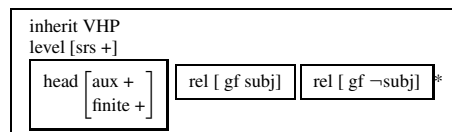
In terms of PG, this construction can be detailed as a set of such constraints:

1. V[aux] ≺ NP[subj]
2. NP[subj] ≺ V[¬fin]
3. V[aux] ⇒ NP[subj]
4. V[¬fin] ≺ XP[¬sub]
5. NP[subj] ≺ Adv[neg,¬contraction]

6. NP[subj] $\prec$ Adv[¬neg]
7. NP $\rightsquigarrow$ V
8. Adv $\rightsquigarrow$ V

This subset of constraints {1,2,4,7,8} represents the information of the SAI construction represented above and we can say that these two notations are equivalent. Adding new information simply consists in adding new constraints to the set describing the construction, at the same level. In this example, on top of these general constraints, it is necessary to specify some constraints. For example, the negative form has to be contracted here. This constraint is imperative in this construction, whereas it can be optional in other cases. This constitutes one important interest in the perspective of associating constraints with an "importance" degree: such degree may vary according to the construction. Using the terminology of [Sorace04], a constraint can be hard in some construction or soft in some others.

3 Gradience and Density

A fully constraint-based representation may also be helpful in identifying criteria for sentence complexity as well as acceptability. The idea is to make use of the information contained in characterizations in terms of satisfied and violated constraints. More precisely, some figures can be extracted from these characterizations illustrating the difference in the realization of a given category. For example, the ratio of satisfied/violated constraints is obviously of main interest.

(10) Quelles histoires Paul a-t-il écrites ?

What stories Paul did he write[fem-plu]? / What stories did Paul write?

(11) Quelles histoires Paul a-t-il écrit ?

What stories Paul did he write[masc-sing]? / What stories did Paul write?

(12) Quelles histoires a-t-il écrites Paul ?

What stories did he write[fem-plu] Paul? / What stories did he write Paul?

(13) Quelles histoires a-t-il Paul écrites

What stories did he Paul write[fem-plu]? / What stories did he Paul write?

These examples are given in order of (un)acceptability which corresponds in our hypothesis to a progressively greater number of violated constraints. Constraints are given here without taking into account specificities of the interrogative construction.

(11) NP[obj] $\rightsquigarrow$ VP[ppas]
(12) NP[subj] $\prec$ VP
(13) NP[subj] $\prec$ VP, V $\not\Leftrightarrow$ NP[subj]

Even without a precise evaluation of the consequence of constraint violations type by type, this first criterion can constitute an objective element of estimation for acceptability: unacceptability increases with the number of constraint violations (Keller's property of *Cumulativity*). This indication seems trivial, but directly comes from the possibility of representing separately the different types of syntactic information by means of properties. Such estimation is for example not possible with a phrase-structure representation and even difficult using classical constraint-based approaches such as HPSG.

However, it is necessary to have a finer-grained use of such information. In particular, the number of constraints may vary from one category to another. Some categories, such as adverbial phrases are very static and are described with a limited number of properties. At the opposite, the noun phrase, that can have many different forms, needs an important number of properties. It is then necessary to distinguish the number of constraint violation in these cases: violating a constraint for an AdvP has more consequences on acceptability than for the NP. Again, this indication is purely quantitative and doesn't take into account constraint type. It is probably the case that some constraints (for example exclusion) play a more important role on acceptability than dependency for example. However, when taking into consideration interpretability for example, a hard constraint such as unicity with respect to acceptability becomes soft for the interpretation, as shown in the following examples:

(14) Paul reads a book

(15) Paul reads reads a book

The second example is obviously unacceptable but perfectly understandable. We propose then a first stage in the identification of gradient criterion by means of purely quantitative aspects. This is the role played by the notion of *density*. This information indicates two figures: the number of satisfied properties with respect to the total number of properties that described the object and the same ratio for violated properties. We note respectively these figures as `dens_sat` and `dens_unsat` with the following definitions:

- `dens_sat` = nb of satisfied properties / total nb of properties
- `dens_unsat` = nb of unsatisfied properties / total nb of properties

To some extent the notion of density can be compared to the one of recall, which is used in evaluation.
Density in itself, at the difference with the ratio satisfied/violated properties, gives some indication about the quantity of information of a given object. In the case of a high density of satisfied properties, this means that an important number of syntactic characteristics contained in the grammar is realized in the object. In other words, we can say that this object contains, with respect to the grammar, important syntactic information. Reciprocally, a low density of satisfied properties can have different interpretations. In case of a high density of violated constraints, the object is clearly ill-formed and we can suspect a low probability for its acceptability. But it can also be the case that there is a low density for violated constraints. This situation indicated that the object contains little syntactic information. In the following example, extracted from a corpus analysis, the category, a sentence, is formed with a PP and a VP:

(16) En renforçant le projet, avançons vers le succès.
in reinforcing the project, let's go toward the success

Cat	`dens_sat`	`dens_unsat`	construction
S	0,5	0,125	PP; VP

Such a construction is not frequent, but some information can be given, according to the grammar. Concerning the violated properties, the non-null density comes from the fact that there is a dependency relation between the VP and a NP subject which is not realized. The level of satisfied properties density comes from the fact that even if the

properties involving PP and VP are satisfied, many properties describing S involve an NP. There is then a high number of properties for S that cannot be evaluated, explaining a low `dens_sat`.

These different ratios constitute then a first tool providing some indication on acceptability and interpretability. Acceptability primarily depends on the ratio of satisfied constraints with respect to the number of violated ones. Interpretability can be illustrated by the densities of satisfied and violated constraints. Low densities, as shown above, indicate a low level of syntactic information. More generally, there is a correlation between the quantity of information contained by an object and its interpretability: a high density of satisfied constraints comes with an easier interpretation. In case of low densities, it is necessary to obtain information from other domains such as prosody.

Using these different indications makes it possible to give information about any kind of input, without any restriction to well-formed ones. Moreover, it becomes possible to propose quantitative elements towards gradience in linguistic data concerning both acceptability and interpretability. Moreover, such elements of information give also some indication about domain interaction. For some utterances, it is necessary to extract information from the different linguistic domains such as morphology, syntax, prosody or pragmatics. In some other cases, the morpho-syntactic level alone contains enough information in order to make an utterance interpretable. In other words, there is a balance among the different domains. Each domain can be characterized with densities such as the one described here for syntax, the balance status being a function of the different densities. A high density of satisfied properties for one domain is an indication of a high level of information. The hypothesis stipulates that in this case, other domains can contain a low level of information without consequence on the interpretability. For example, for some construction, if there is a high density in syntax and semantics, then the density of prosody is not constrained and can take any value. Concretely, this means that intonation is not constrained anymore and can be realized in various ways. On the contrary, when syntactic and semantic densities are not heavy enough, then the prosody density has to be high and the intonation is less variable. This is the case in the example (3) for which prosody plays an important role in the interpretation.

4 Experiment

In the following, we give some indications from different French corpora, calculated from the output of a deterministic property grammar parser (see [Blache01] for a description of this parser). One important restriction is that, insofar as the parser used is deterministic, the number of violated constraints has been restricted to a minimal level. In particular, only the linearity, exclusion and unicity constraints have to be satisfied. The density of violated constraints is therefore not relevant for our discussion. We take then only into account the density of satisfied constraints. The aim of this experiment is to extract some figures from different data, for a given grammar and a given parser. It cannot be considered as a parser (or grammar) evaluation.

Three different corpora have been used: the first from the newspaper "Le Monde ', with 15,420 words, the two others are transcribed spoken language corpora containing respectively 523 and 1,923 words. These corpora are very small, which is justified by

the difficulty in parsing such data. Moreover, they have been filtered: incomplete words for example have been eliminated. However, all repetitions are kept.

The first observation in this experiment is that, even if most of the categories have a null density (for the reasons explained above), there is a huge difference among the densities of satisfied constraints. The following table indicates for example some figures concerning the noun phrase in the written text corpus:

Density	Const	Density	Const
0.034483	PPro	0.310345	Det AP PP
0.068966	Clit	0.379310	Det N Rel
0.103448	N	0.413793	Det AP N
0.1724138	ProP AP	0.413793	Det N PP
0.206897	Det AP	0.517241	Det N Rel PP
0.241379	Det PP Rel	0.551724	Det N AP PP
0.275862	Det N	0.655172	Det N PP AP Rel

In these figures, one can remark that density doesn't grow systematically with grammaticality. For example, the two lowest densities correspond to grammatical constructions (personal pronoun and clitic). This comes from the fact that the noun phrase, which is the most frequent category, has many different constructions and needs a lot of constraints to describe them. In all cases, even when a given construction satisfied all its corresponding constraints, insofar as the total number of constraints for the NP is high, the density is necessarily low. Moreover, the realizations observed here only contain one category. The total number of satisfied properties is then by definition very low without having any consequence on the grammaticality (which should be indicated by the ratio satisfied/violated constraints). The same explanation is valid when comparing the realization /Det N/ with /Det N PP/. The first has a lower density whereas one should expect a high one for this basic construction. Frequency information plays then an important role in the use of the density notion. The following table indicates the mean density with respect to the frequency of the category in the different corpora:

Cat	Frequency	Density
S	0.069917582	0.4733535
AP	0.108379121	0.408556
AdvP	0.048139361	1
NP	0.302047952	0.204571
PP	0.1003996	0.31331
VP	0.218981019	0.341995
Circ	0.064360639	0.718518
Coord	0.071978022	0.4821425
Rel	0.015796703	0.3543475

We can see in this table that the most frequent categories (NP, VP and PP) are also those with the lowest mean density whereas the less frequent ones (Circ, AdvP and Coord) are associated with high densities. The arguments given above concerning the number of constituents, the number of properties and the number of different constructions can be used for explaining these differences.

This density parameter has then to be modulated with the frequency of the construction. In all cases, the progression of the density comes with an increasing quantity of

information. It is important to notice that the density notion is not directly useful in the identification of sentence complexity. For example, one can consider that a realization of a NP with a relative clause is more complex than a construction /Det N/. However, the first has a higher density than the second, for the reasons explained above. But from the interpretability point view, these aspects are disconnected. For example, a cleft construction, which is identified as being complex, is easily understandable because of the high number of constraints describing it. The following examples illustrate some density differences from a construction with few constraints to be satisfied and another containing more information:

Example	Density
(16) celui rouge *that red*	0,1724138
(17) Le contenu de la future con- vention qui devrait permettre de régler les problèmes de fond *the content of the future con- vention that may allow to solve problems in depth*	0,6551724

5 Further Works

Intuitively, the notion of density could be refined by weighting the constraints according to their importance. The hard/soft discrimination ([Sorace04]), for instance, is not accounted at the moment by the density whereas we have seen previously that the constraints play roles of different importance when it comes to acceptability. Some sort of constraint ranking would also let us model the cumulativity and ganging up effects (i.e. when multiple violations of soft constraints could possibly be more unacceptable than a single violation of a hard constraint) described by [Sorace04].

Another object of further investigation concerns the use of weighted densities during the parsing process as an element of disambiguation. Indeed when faced with different possible assignments heuristics could be based on the measure of density for each possibility in order to rank the structures by preference. Subsequently a deterministic approach, of course, could also use this preferred structure to reduce the search space at different stages in the solving process.

6 Conclusion

The constraint-based approach proposed in this paper presents several advantages. In particular, all information is represented by means of constraints. Moreover, these constraints are at the same level (there is no ranking between them) and the grammar is formed by the constraint system. In contrast with other holistic approaches, each constraint can then be evaluated separately. Concretely, this means that syntactic information can be built for any input, whatever its form. Moreover, such information can be quantified and gives some indications about acceptability (high ratio satisfied/violated constraints) and interpretability (high density of satisfied constraints). One of the interests of this approach is that such information can be modulated. For example, it has

been shown that the importance of some constraints may vary from one construction (represented in our approach as a subset of constraints) to another.

From a cognitive point of view, the use of a fully constraint-based system may have some interest in terms of modeling. Constraints play the role of a filtering process: linguistic information does not consist in defining all and only the possible constructions, but in indicating for some construction what kind of information can be extracted. This means that in some cases (at least theoretically), little (or no) information can be extracted from one domain. But even in this case, such utterances can be treated.

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