Active Constraints for a Direct Interpretation of HPSG

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1 Introduction

Implementing a linguistic theory raises (at least implicitly) the question of the interpretation level. Evans87 distinguishes indirect, weak direct and strong direct interpretations: the former uses an intermediate mapping between the original theory and the grammars whereas the latter treats the grammars as directly characterising the language. Practically, the better the adequacy between linguistic and computational models, the higher the directness level

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An indirect interpretation compiles the original formalism into another one (e.g. an HPSG grammar into a simple phrase structure one) in order to apply traditional parsing techniques. A strong direct interpretation implements parsing mechanisms as described in the theory.

We argue in this paper that high-level languages can provide a good adequacy between the theory and its implementation. We approach in particular the question of constraints implementation and show how constraint logic programming (and more particularly multi-paradigm languages such as LIFE) constitutes an efficient implementation framework. This paper describes how such a direct approach preserves the fundamental properties of the linguistic theory.

2 Indirect vs. Direct Interpretations

Most of the implementations rely on indirect or weak direct interpretations and generally compile the original formalism into Prolog clauses (see for example Carpenter93, Götz95 or Popowich91). We can distinguish two different approaches according to the level of the implementation. One method consists of implementing the parser using a high-level language and relying on mechanisms as close as possible to the theory. In this case, the language is used both for the knowledge representation (i.e. coding the grammar) and the implementation of parsing mechanisms. The second approach proposes specific languages used for representing grammars and generates parsers using a low-level language

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The figure presents these approaches.

We think that there is a deep difference between them from several point of view concerning in particular faithfulness, generality and control. Our argumentation relies on the observation of the parsers architecture and more particularly on the specification of the mechanisms required by HPSG. We distinguish the fundamental characteristics of a theory from the corresponding operational concepts. As for HPSG, the basic notions are universal principles, structure sharing, sort hierarchy, well-typedness, etc. Their implementation requires specific mechanisms such as in particular unification, constraint propagation, constraint satisfaction, inheritance, underspecification,

1In the same perspective, Fong91 completes directeness with the notion of faithfulness.

2In the case of ALE, the parser is generated in Prolog but uses low-level instruction. In fact, as proposed by the authors (see Carpenter94), the host language should be C.
delayed evaluation, etc. The adequacy between these two levels seems to be very important both for linguistics and computational reasons.

2.1 Faithfulness

Faithfulness, and more precisely the adequacy between the theoretical model and its implementation, can be considered as a non formal criterion and evaluated from a formal and an operational point of view. From a formal point of view, a faithful approach applies directly the parsing algorithm to the original grammar whereas an indirect interpretation generates a grammar relying on another formalism. This difference is not purely esthetic: a direct approach implements and validates the model.

As for the operational point of view, we think that faithfulness preserves in the implementation the properties of the theory itself. Let us precise this aspect for HPSG by focusing on two important characteristics: generality and integration.

- **Generality** concerns the ability of representing universal phenomena. This property is in fact closely related to the reusability which concerns both the linguistic level (reusing different grammars) and the computational one (reusing the same parser for different grammars).

  A faithful implementation preserves the generality level of the mechanisms (and their reusability) in the sense that if the theory describes a general high-level property (e.g. universal principles), then the corresponding mechanism is at the same level (e.g. active constraint on types). This entails a distinction between the architecture of the feature structures and the constraints that they must satisfy: on the one hand, a feature structure must be totally well-typed (architectural property) and correspond to an ID-schema, on the other hand, it must satisfy the universal principles. A faithful implementation using active constraints (in the constraint programming sense) allows such a distinction whereas a Prolog implementation cannot separate these levels: in this case, principle verification is evaluated after the instantiation of the concerned feature structure (for this reason, as in ALE, universal principles often belong the description of the ID-schematas).

- The second property, **integration**, concerns the ability of representing in an homogeneous way different source of linguistic knowledge: prosody, phonology, morphology, syntax, se-
mantics, etc. This property, as for generality, relies on the distinction between structures and constraints: integrated approaches must represent various kind of informations within a same structure. The relations between these informations are described using constraints. But there is another important aspect concerning the dynamicity of these relations. Indeed, an integrated approach must describe mutual dependencies between the different levels of information. These relations have consequences on the structure itself (in particular via structure sharing), but also on the processes constructing the corresponding structure. For example, syntactic informations can have consequences at the phoneme recognition level. This characteristic entails an on-line process and a direct manipulation of the original structures.

2.2 Control

The control problem constitutes another divergent criterion between direct and indirect approaches. Several aspects can be underlined.

The first point is theoretical and concerns the system architecture. The figure (1) indicates that the grammar developer in the case of an indirect system encodes the grammar into a specific formalism. The compiler then generates the parser itself. It is considered as a black box and the semantic is not accessible to the grammar developer who has no control on the parser itself. In the case of direct approaches, the developer knows the semantic of the language and has a direct control on the parser.

The second aspect concerns more precisely the implementation level. The current state of parsing technologies shows that we need a clear distinction between the linguistic knowledge (including architectural aspects) and the implementation mechanisms. Practically, as shown in the figure (1), this separation is present in the parsers. The problem comes from the fact that in the case of an indirect approach, it is not always possible to apply such a distinction. This is the case for the application of the principles. Their possible presence in the ID-schematas is only justified by the fact that Prolog cannot represent directly constraints on types and must verify such properties on instantiated object. At the opposite, a language providing active constraints on types allows the declaration of such constraints a priori, in a global and persistent way.

We can generalize this last remark to the adequacy between the mechanisms required by HPSG and those actually implemented. If the host language of the system doesn’t provide adequate mechanisms, they are simulated (e.g. inheritance becomes an inference process).

Finally, indirect approaches need an interpretation of both formalisms and mechanisms. We think that before the efficiency problem (which is the main argument for indirect approaches), the actual problem for the implementation concerns the preservation of the theory’s generality (of great importance in particular concerning reusability and maintenance).

3 A Constraint Logic Programming Solution

As described in the previous section, coding a grammar concerns knowledge representation but also interpretation of the implicit mechanisms of the theory. The question is now: is it possible to directly code a HPSG grammar into a high-level language or must we use a specific language? We describe in this section a solution proposed within the constraint logic programming paradigm.

3.1 Active constraints

HPSG generally considers constraints as descriptions that a well formed object must satisfy (see Carpenter92). In this definition, the notion of constraint is very precise and restrictive in comparison with the traditional sense in linguistics. But it has a direct interpretation within the constraint programming paradigm with active constraint. We present this notion in this section and compare it with traditional approaches.
The classical evaluation method in logic programming relies on generate-and-test: it generates variable values before verifying their properties. Obviously, a value can be controlled by unification with the head of the predicate, but it is impossible to evaluate properties (i) before the unification itself and (ii) if the object represented by the variable is only partially known.

Active constraints can implement some of these properties and reduce the search space by applying them a priori: substitutions are allowed only if the constraint system remains coherent. In a constraint logic programming paradigm, the constraint satisfaction mechanism replaces unification: each resolution step verifies the satisfiability of the constraint system and simplifies it. Binding a variable adds new constraints to this system. In other words, the classical method in Prolog uses a single kind of constraints (unification) whereas a constraint-based approach allows the definition of complex ones with a global scope.

Concerning HPSG, a direct interpretation consists of implementing principles with active constraints. This approach allows a clear distinction between the basic parsing mechanisms and the control level. The parse level consists of determining the possible relations (basically the valency) whereas constraints verify the well formedness of the structure. Insofar as constraints are active, such a verification has two main characteristics: it is an on-line process and it doesn’t need any extra resolution step. Indeed, a classical Prolog implementation explicitly verifies the well-formedness using a set of predicates whereas a constraint approach verifies the satisfiability of the constraint system and unifies two terms in a single resolution step. It is clear that the evaluation of the constraint system satisfiability has a cost, but lower than a classical method because (i) the system can be simplified (whereas a classical resolution requires the evaluation of all the properties) and (ii) the search space is reduced a priori (this improves the control level).

3.2 Implementation in LIFE

The basic mechanisms required for a direct HPSG interpretation are in particular unification, constraint satisfaction and inheritance. As for knowledge representation, the basic objects are the typed feature structures. The language LIFE (cf. [A¨ıt-Kaci91]) implements all these requirements. It is a multi-paradigm language (functional, logic, constraint, object oriented paradigms) which uses the ψ-terms as basic objects. LIFE offers built-in inheritance together with constraint solving mechanisms: these characteristics allow (i) to constrain the terms and (ii) to control propagation.

The following points are just a sketch illustrating the relevance of this framework for a direct interpretation.

3.2.1 Principles

In this language, constraints are expressed on the sorts: descriptions corresponding to principles are implemented directly in this way. We can remark that the formulation of these principles are very similar in all the system implementing HPSG. The difference here doesn’t concern the representation but the evaluation. We take here the case of two basic principles implemented as active constraints on the type phrase. Each term of this type must satisfy these constraints even if it is not instantiated.

**HFP:**

$$:: \text{P: phrase} | (\text{P.synsem.loc.cat.head = X}, \text{P.dtrs.head-dtr.loc.cat.head = X}).$$

Such a constraint stipulates that every term of sort phrase must have the concerned head values refering to the same term (tagged by X).

**Valency Principle:**
This principle has also a classical formulation, very close to that proposed in other approaches which is not surprising. What is interesting here is the use of the function `append` which residuates if its arguments are unsufficiently known. This constraint can therefore be applied a priori and the instantiation of one of the concerned features fires the evaluation of the function and install the constraint.

In a classical Prolog implementation, these principles are verified after the construction of each phrasal sign. In LIFE, these constraints are (automatically) satisfied at each moment by these terms. The satisfiability is not evaluated after the complete instantiation of the term but checked at each step since its creation: incoherences are detected sooner than for classical generate-and-test approaches.

### 3.2.2 Inheritance

Inheritance relations allows the specification (and the propagation) of several properties. A well-formed sign must satisfy principles together with these properties.

Inheritance in LIFE can be seen as a constraint in the sense that it is integrated to the unification algorithm. This improves a classical Prolog approach because, as shown in [Ait-Kaci86], inheritance is processed by unification steps instead of resolution ones.

Practically, we implement directly the sort hierarchy using sort inheritance definitions as described in the theory.

```prolog
lex < | sign. phrase < | sign.
noun < | subst. subst < | head.
...
```

Each sort being possibly constrained with a particular property, this mechanism can implement, as in the theory, complex description relying on multiple inheritance.

### 3.2.3 Sort Resolution and Appropriateness

HPSG defines both sort hierarchies and features appropriated to each sort. LIFE allows to closely follow HPSG’s definitions by (i) defining sort inheritance hierarchy and (ii) constraining features associated to them. For example, we declare the `substantive` sort which subsorts are `noun`, `verb`, `adjective`, `preposition` and `relativizer`. Then we pose the constraint about the sort `category`, which HEAD feature must be of sort lower than `substantive`.

```prolog
substantive := noun;verb;adj;prep;reltvzr.
:: C:category(head => substantive) | C.head :< substantive.
```

However, LIFE permits to dynamically enlarge feature structures unlike HPSG where feature structures are canonical. To constrain LIFE to have at most the feature appropriated to a structure, we pose some additional constraints.

```prolog
:: C:category | lmember(features(C), [head,valence,marking]).
```

Then, the sort `category` is constrained to have at most the HEAD, VALENCE and MARKING features as defined in the theory. The `lmember` predicate parses the authorized features list and succeed if all features of `C` belong to it.
4 Conclusion

Our approach shows that a strong direct interpretation can be efficient in several respects. First, the implementation framework is an actual programming language which avoid the development of translation tools. Second, a direct interpretation allows a good maintenance and reusability of the systems in particular because the generality of the theoretical framework is preserved. Finally the constraint programming paradigm offers very efficient properties useful particularly for knowledge representation and control. To summarize, the implementation of linguistic constraint using active constraint is concise, faithful and efficient.

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