SYMBOLIC COMPUTATION

Harvey Abramson
Veronica Dahl

# Logic Grammars

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To Lynn, and also to Cali who helped with the reading.

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# PART 0

# INTRODUCTION AND HISTORIC OVERVIEW

The principles of logic programming have been applied to formal and natural language processing since 1972, mainly through the Prolog language. Starting from applications such as question answering systems, many interesting problems in natural language understanding were studied with the new insight that logic is a programming tool – an insight very much in line with previous uses of logic in computational linguistics. Thus, areas such as formal representations of natural language, grammar formalisms, methods for analysis and generation, and even very specific linguistic aspects such as coordination evolved in directions typical of the context of logic and of logic programming. In the formal language area, logic grammars have been used for implementing recognizers and compilers, also with good results, particularly in the conciseness of the systems obtained.

Traditionally, logic was considered one of the most appropriate tools for representing meaning, due to its ability to deal formally with the notion of logical consequence. Representing questions and answers in logical form typically required some extensions to classical predicate calculus. In the recent past, logic was also used to represent the information to be consulted in question-answering systems. Here also, departures from first order logic were necessary, and in general, parsing knowledge, world knowledge and the meaning of questions and answers were represented and handled through quite different formalisms, resulting in the need for interfaces to link them together.

The introduction of Prolog (PROgrammation en LOGique) by Colmerauer and others made it possible to use logic throughout, minimizing interfaces from one formalism to another. World knowledge can be represented in logical form, through facts and rules of inference from which a Prolog processor can make its own deductions as needed. Extracting logical consequences amounts to hypothesizing them and letting Prolog deduce, from the facts and rules stored, whether they indeed are logical consequences, and, if they are, in which particular instances. Questioning and answering reduces to hypothesizing the question's content and letting Prolog extract instances, if any, that make the question true with respect to the world described. Those instances become answers to the question.

Parsing itself can be left to Prolog, by representing it as a deductive process – i.e., grammars can be described as facts and rules of inference, and sentence recognition reduces to hypothesizing that the sentence in question does belong to the language, and letting Prolog prove this assumption.

The Prolog equivalent of grammar symbols, moreover, are logic structures rather than simple identifiers. This means that their arguments can be used to show and build up meaning representation, to enforce syntactic and semantic agreement, etc. In other words, the very nature of Prolog facts and rules allow us to retrieve instances from parsing that can tell us more than mere recognition: logical

representation of the sentences recognized, causes of rejection, such as semantic anomaly, etc. Thus Prolog is eminently suitable for linguistic work.

Nevertheless, writing substantial grammars in Prolog that could in practice be used as parsers did require knowledge of the language (i.e., a computer specialist's mediation), and involved caring for details that belong to the nature of Prolog's mechanism rather than to considerations of linguistics or the parsing process proper.

The introduction of metamorphosis grammars by A. Colmerauer in 1975 was the first step in making Prolog a higher level grammar description tool. Although these grammars are basically a syntactic variant of Prolog, they achieve two important improvements with respect to Prolog's syntax:

1. They allow the direct writing of type-0–like rules (in the sense of Chomsky's formal grammar classification); these rules can have more than one symbol on the left hand side.
2. They hide string manipulation concerns from the user.

Prolog grammars can now be thought of as rewriting mechanisms which assemble and manipulate trees rather than as mere procedures to be described in terms of Prolog rules and facts. In present implementations, logic grammars are automatically translated into Prolog, but they still remain a distinct formalism in their own right, and they do make life easier for the non-computer specialist–e.g., for linguists.

In 1975 then, all the pieces were laid out to build a new synthesis in the design and implementation of natural language consultable knowledge systems. A. Colmerauer exemplified in a toy system about family and friendship relationships how these pieces could be put together. One of the authors, V. Dahl, developed the first sizeable applications of this new synthesis: first an expert system for configuring computer systems, together with R. Sambuc, and then a data base system with French and Spanish front ends. Both systems were written entirely in Prolog. Logic was used throughout: as a programming tool, as the means for knowledge representation, as the language for representation of meaning for queries, and (in the form of Prolog's hidden deductive process) as the parsing and data retrieval mechanism.

Not all of these uses involved the same type of logic: for natural language representation, Dahl used a three-valued set-oriented logical system; for knowledge representation, she developed some Prolog extensions such as domains, set handling primitives, etc. Yet other developments were needed to solve problems specific to Prolog, such as dealing with negation and modifying Prolog's strict left-to-right execution strategy in order to provide a more intelligent and efficient behavior.

These extensions, as well as the link between different logic formalisms used in these systems, were also hidden from the user. From an implementation point of view, the fact that logic was used throughout made the linking of different formalisms a much simpler task than in typical data base systems, resulting in a concise formulation. For instance, the three-valued logic mentioned above was

implemented through a Prolog definition of how to evaluate its expressions, which took less than a page of code.

These techniques were soon exported to other data base and expert systems consultable in other languages (English, Portugese, etc); the main feature of the application of these techniques was the striking ease with which the transposition was achieved. An English adaptation of this system was used in a key paper by F. Pereira and D. Warren–"Definite Clause Grammars for Language Analysis." This article analyzed the logic grammar approach and compared it with the Augmented Transition Network approach, concluding that the former approach was superior.

These encouraging results prompted further research: the techniques for language analysis and for modifying execution strategy were adapted into the CHAT-80 system. M. McCord systematized and perfected the notion of slots and modifiers that had been used in the earliest analyzers, achieving a more flexible strategy for determining scope; F. Pereira developed the *extraposition grammar* formalism, specifically designed to make left extraposition descriptions easier. Dahl and McCord then joined efforts to produce a metagrammatical treatment of coordination in logic grammars, and developed as a by-product a new type of them called *modifier structure grammars* (MSGs), these are essentially extraposition rules in which the semantic components are modularly separated from the syntactic ones, and for which the building of semantic and syntactic structure, as well as the treatment of quantifier scoping, of coordination, and of the interaction between the two, is automated. Further work on coordination was produced by C. Sedogbo and L. Hirschman. The notion of automatic structure buildup that resulted from Dahl and McCord's work on coordination was isolated by H. Abramson into the *definite clause translation grammar* formalism (DCTGs). In it, natural language processing power is traded for simplicity (e.g., quantifier scoping, coordination and extraposition are no longer automated), but for other applications, semantic structure buildup is usually enough. The separation between syntactic and semantic rules is also mentioned.

In 1981, V. Dahl generalized extraposition grammars into a more powerful formalism, called *discontinuous grammars*,[1] that can deal with multiple phenomena involving discontinuity: left and right extraposition, free word order, more concise descriptions, etc. Implementation issues were investigated jointly by the authors, by Dahl and McCord, and by F. Popowich. A constrained version of these grammars was investigated by Dahl and Saint-Dizier.

A more interesting subclass of the *discontinuous grammar* family was developed by Dahl and investigated within her research group for the purpose of sentence generation using Chomsky's Government and Binding theory: *static discontinuity grammars* (SDGs). In this subclass, movement phenomena can be described statically, and the power of type-0 rules coexists with the representational simplicity of context-free–like rules (i.e., trees rather than graphs can depict a sentence's

[1] The early publications use the term *gapping* instead of *discontinuous*. This name was changed in order to avoid evoking the wrong associations, since the linguistic notion of *gap* is a different one.

derivation). Hierarchical relationships, crucial to linguistic constraints in general, are thus not lost, and linguistic theories can be accommodated more readily, by expressing these constraints in terms of node domination relationships in the parse tree.

Bottom-up parsing has been investigated by A. Porto et al., Y. Matsumoto et al. and K. Uehara et al. Miyoshi and Furukawa have developed another logic programming language specifically suited for object oriented parsing. M. Filgueiras has studied the use of cooperating rewrite processes for language analysis.

The field is active and promising. This book intends both to introduce the main concepts involving language processing developments in Prolog, and to discuss the problems typically encountered and some of the alternatives for solving them.

After an in-depth presentation of the basic material, we provide a wide rather than deep coverage of many of the related topics. Some bibliographic references are mentioned within the text at places where they are directly relevant, and at the end of each part we complete the picture with other relevant bibliographic comments.

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# PART I

# GRAMMARS FOR FORMAL LANGUAGES AND LINGUISTIC RESEARCH

## Chapter 1

## What Are Logic Grammars?

### 1. Logic Grammars – Basic Features

Logic grammars can be thought of as ordinary grammars in the sense of formal language theory, in that they comprise generalized type-0 rewriting rules–rules of the form : "rewrite $\alpha$ into $\beta$," noted:

$$\alpha \rightarrow \beta$$

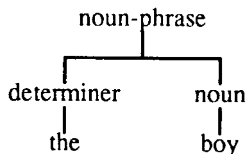
where $\alpha$ and $\beta$ are strings of terminals and nonterminals. A terminal indicates a word in the input sequence. A sequence of terminals takes the form of a Prolog list. Nonterminals indicate constituents. In this text, they take the form of a Prolog structure, where the functor names the category of the constituent and the arguments give information like number class, meaning etc.

Logic grammars differ from traditional grammars in four important respects:

1. The form of grammar symbols, which may include arguments representing trees
2. The use of variables, involving unification
3. The possibility of including tests in a rule
4. The existence of processors based on specialized theorem - provers that endow the rules with a procedural meaning by which they become parsers or synthesizers as well as descriptors for a language (e.g., Prolog and its metalevel extensions)

### 2. Grammar Symbols

Logic grammar symbols, whether terminal or nonterminal, may include arguments (as opposed to the formal grammars of Chomsky's hierarchy). One of the uses of these arguments is to construct tree structures in the course of parsing. A tree such as



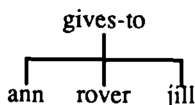
is represented in functional notation:

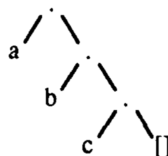
noun-phrase(determiner(the),noun(boy))

More generally, arguments have the form:

root($t_1, \cdots, t_n$)

where *root* is an $n$-ary function symbol (in our example, the binary symbol *noun–phrase*), and the $t_i$s are arguments, which in turn represent trees. Note that *argument* is used recursively. By convention (as in Prolog) arguments written in lower case are *constants*. An argument can also be a *variable*, in which case it stands for a particular but unidentified tree or constant. Variable names start with a capital. When $n=0$ (i.e., when the root has no branches), the argument is a constant (e.g. "the," "boy") or a tree consisting of just the root. Here are two more sample trees and their functional representations: (Terminal symbols are noted in square brackets.)




gives-to(ann,rover,jill) .(a,.(b,.(c,[])))

In the second of these, the root is the symbol ".", usually used to denote "concatenation." Trees constructed with this binary symbol, as above, are called *lists* and, in logic grammar are interpreted as a string of terminals. They have the simpler equivalent notation:

[a,b,c]

Summarizing, a logic grammar symbol has the form:

name($t_1, \cdots, t_n$)

where the arguments $t_i$ are either constants, variables, or trees in functional notation. Terminal symbols are enclosed in square brackets to distinguish them from nonterminal ones.

Here are some (unrelated) sample logic grammar rules:

1. verb(regarder) --> [look].
2. verb(third,singular,regarder) --> [looks].
3. a,[b] --> [b],a.

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