CHR as grammar formalism

A first report

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Abstract. Grammars written as Constraint Handling Rules (CHR) can
be executed as efficient and robust bottom-up parsers that provide a
straightforward, non-backtracking treatment of ambiguity. Abduction
with integrity constraints as well as other dynamic hypothesis gener-
ation techniques fit naturally into such grammars and are exemplified
for anaphora resolution, coordination and text interpretation.

1 Introduction

The language of Constraint Handling Rules [16,17], CHR, was introduced as a
tool for writing constraint solvers for traditional constraint domains such as real
or integer number arithmetic and finite domains. CHR, however, has turned out
to be of more general value and is now available as an extension of among others,
SICStus Prolog [27]. The CHR web pages [8] contains a growing collection of
applications. Being of special interest to language processing, [3] has shown that
CHR adds bottom-up evaluation to Prolog and a flexibility to combine top-
down and bottom-up; [2] has taken this a step further showing that abduction
and integrity constraints can be expressed in a straightforward way in CHR.

Here we investigate CHR applied as a grammatical formalism and it appears
that a grammar can be written in a straightforward way as propagation rules of
CHR that execute as a robust bottom-up parser which handles ambiguity with-
out backtracking. Constructed in the most naive way, these parsers are of a high
time-complexity, typically cubic or worse, but by means the so-called pragmas
provided by current implementations of CHR, realistic and almost linear parsers
are achieved, executing quite similiary to shift-reduce parsers.

Look-ahead techniques are easily expressed and ambiguous grammars can
be made unambiguous using simplification rules instead of propagation rules.
Similarly as for Definite Clause Grammars [26] (DCGs), CHR grammars (as we
deliberately call them) can take arbitrary attributes in a similar way but ac-
cepts a wider class of context-free bases. Except for direct loops in the grammar,
CHR grammars works correctly for any such basis. As is well-known, DCG’s
top-down evaluation with backtracking may lead to combinatorial explosion in
time which is avoided by a bottom-up evaluation that examines all hypotheses
in the same space. However, there are other and more significant differences,
most importantly the way in which arbitrary hypotheses can be produced and consumed in CHR and applied for controlling the parser and for evaluation of semantics. Assumption grammars [12] that use linear and intuitionistic assumptions in various ways can be implemented very easily in CHR and abduction with integrity constraints works fine as well. Examples are given of anaphora resolution, coordination, and text interpretation by abduction.

Related work

The notion of constraints, with slightly different meanings, is often associated with language processing. “Constraint grammars” and “unification grammars” is often used for feature structure grammars and constraint programming techniques have been applied for the complex constraints that arise in natural language processing, see, e.g., [4,13] for introduction and overview. Constraint logic programming, in terms of using black-box constraint solvers, has been applied at many occasions as well.

What we propose is to capture fundamental processes such as parsing and semantic analysis by means of declaratively specified constraint solvers, more specifically, expressed and implemented in the language of CHR. While our results are promising, there is still very little work to report in this context. The basic principle of using CHR’s propagation rules for context-free parsing has also been suggested by [23] but not elaborated further; [25] has used CHR for evaluation of feature structures for HPSG.

Assumption Grammars [12], inspired by Linear Logic, provide a structured way to generate and manage dynamically generated hypotheses. This provides elegant solutions to problems that are otherwise difficult to handle, although there seems to be a need for more detailed methods to control the scope of such hypotheses. We do not provide new suggestion for this, but it seems possible to implement a variety of such mechanisms in our CHR based framework.

The close similarity between our representation of abduction and of Assumption Grammars in CHR seems to indicate a closer relation between the two that still needs to be investigated. References related to abduction are given in section 5.

Overview

Section 2 explains how propagation rules provide obviously correct parsers and section 3 concerns their time complexity. Section 4 shows how assumption grammars can be implemented and discusses some improvements and section 5 introduces abduction and integrity constraints into the model. The final section 6 provides a summary and discusses possible syntactic sugar for CHR grammars and other perspectives. No introduction to CHR is given; we refer to [16,17] or online manuals [8,27].
2 CHR as grammar formalism: The basic principle

A set $P$ of propagation rules of CHR constitutes a natural bottom-up evaluator: The set of initial hypotheses $H$ is given as a query and the evaluator produces as answer the set $A$ of all atoms that are logical consequences of $P \cup H$, of course provided that no infinite loop occurs. The set $H$ is the initial constraint store, $A$ the final constraint store in which all rules of $P$ that can apply have been applied.

Using CHR for parsing, we represent a string to be analyzed as a set of initial constraints of the form $\text{token}(t,n-1,n)$, where $t$ is a Prolog atom and $n-1$, $n$ indicates the position in the string. So, e.g., “Peter likes Mary” is represented as

$\text{token(peter,0,1)}, \text{token(likes,1,2)}, \text{token(mary,2,3)}$.

Nonterminals, say $Q$, of a context-free grammar can be represented as a binary constraint symbol $Q(n,m)$ with the interpretation “substring between positions $n$ and $m$ comprises an instance of $Q$”. Each context-free grammar rule

$Q_0 ::= Q_1, \ldots, Q_k,$

with $k > 0$, $Q_0$ a nonterminal and each $Q_i$, $0 \leq i \leq k$, a terminal or nonterminal, is represented as a propagation rule

$S_1, \ldots, S_k \Rightarrow Q_0(N_0,N_k)$.

where, if $Q_i$ is a terminal, $S_i = \text{token}(Q_i,k-1,k)$, and if $Q_i$ is a nonterminal, $S_i = Q_i(N_i-1,N_i)$.

Empty productions $N ::= \epsilon$ can be handled by inserting $N(0,0)$, $N(1,1)$, etc. in the initial constraint store but in the following we consider only grammars without empty productions. We may distinguish a particular nonterminal of a grammar as its start symbol.

Example: The grammar $\{ \text{sentence ::= np \ verb \ np; np ::= peter | mary; verb ::= likes} \}$ is translated into the following CHR program.

$\text{np(N0,N1)}, \text{verb(N1,N2)}, \text{np(N2,N3)} \Rightarrow \text{sentence(N0,N3)}$.

$\text{token(peter,N0,N1)} \Rightarrow \text{np(N0,N1)}$.

$\text{token(mary, N0,N1)} \Rightarrow \text{np(N0,N1)}$.

$\text{token(likes,N0,N1)} \Rightarrow \text{verb(N0,N1)}$.

A parser given in this way for a context-free grammar $G$ is obviously correct in that the following properties hold: let $t_1 \cdots t_x$ be the input string and $S$ the start symbol.

1. If the grammar contains no loops, i.e., no nonterminal can derive itself, the parser is guaranteed to terminate. Given this premise, we have also:
2. If and only if nonterminal $N$ can generate substring $t_i \cdots t_j$, the final constraint store contains the constraint $N(i,j)$.
3. The final constraint store contains $S(0,x)$ if and only if $S$ can derive $t_1 \cdots t_x$. 
4. If the grammar is ambiguous and a substring \( t_i \cdots t_j \) corresponds to \( n \) different parse trees, each with top node \( N_1, \ldots, N_n \), the final constraint store contains exactly \( n \) constraints with argument list \((i, j)\), namely \( N_1(i, j), \ldots, N_n(i, j)\).

Properties 1 and 3 express the usual notion of correctness for a parser. Property 2 means that the parser is robust in the sense that if the entire string does not conform with the grammar, it is still possible to extract those parts that represent recognizable subphrases. Property 4 shows that ambiguity is handled in a natural way without backtracking; the constraints can be extended with an argument representing a parse tree (or some semantic representation) and all possible trees (or meanings) can be read out of the final state. These properties are desirable especially for natural language processing where the language usually is richer than any grammatical formalization of it and where ambiguity is an inherent property.

However, property 2 shows also that the final constraint store may become quite large as it contains all nonterminals that has been possible to recognize, even in case they do not contribute to the overall parse due to “local ambiguity”. Using such a parser for the grammar \( \{a::=a; a::=a \text{ as}\} \) for a string of length \( n \) will result in a final state with \( n(n + 3)/2 \) constraints.

Extra arguments can be added to the nonterminals in the same way as in a DCG and string indices can be hidden by means of syntactic sugar à la DCG. In the final section, we discuss possible syntactic sugaring, but until then we stay with our goal, namely to investigate the full CHR language as a grammatical formalism. The declarative semantics of CHR provides a semantics for our grammars but we will also refer to the procedural semantics and implemented features for various adjustments.

3 Time complexity and what to do about it

Time complexity for constraint solvers similar to CHR’s propagation rules has been studied by [22]. It is shown that a parser for a context-free grammar in Chomsky Normal Form (max. two grammar symbols on rhs) runs in time \( gn^3 \) where \( g \) is the no. of grammar rules and \( n \) the length of the input string. This conforms with the classical result for the Cocke-Younger-Kasami parsing algorithm that works quite similarly to a parser comprised by propagation rules; see, e.g., [3] for background. We made an empirical test by analyzing random sequences of \( a \)s and \( b \)s with a propagation rule parser for the grammar \( G = \{S::=a \ AB \mid B \ A; A::= B \ BB \mid a; B::= A \ S \mid b; AB::= A \ B; BB::= B \ B\} \). This grammar has an extreme degree of local ambiguity, resulting in an huge number of derived constraints. Our test with SICStus Prolog’s implementation of CHR shows indeed a complexity of \( n^3 \) until an exponential factor takes over around \( n = 30 \), probably due to a very active garbage collector. For \( n = 30 \), the final store contains in average more that 1500 constraints. The complexity increases to higher powers of \( n \) when more grammar symbols appear in each rule.
We believe that more interesting grammars will produce far less final constraints, but still the $n^3$ makes the method unrealistic for any practical application. Fortunately, there are several ways to reduce time complexity that we illustrate for a parser of arithmetic expressions based on a straightforward, ambiguous grammar. One of the rules is the following.

$$\text{exp}(N_0, N_1), \text{token}(+, N_1, N_2), \text{exp}(N_2, N_3) \Rightarrow \text{exp}(N_0, N_3).$$

Current CHR implementations (that do not recognize the pattern of recurrence of the variables) will test this rule twice whenever a new exp is created, once to check if it matches the leftmost exp in the rule and secondly for the rightmost. In addition, the entering of token(+, ⋯) will also result in a check for applicability of the rule.

CHR's so-called pragmas can be applied to force the parser to work more like a classical shift-reduce parser. We do this by making each but the rightmost grammar symbol passive in each rule, e.g.,

$$\text{exp}(N_0, N_1)#\text{Id}_1, \text{token}(+, N_1, N_2)#\text{Id}_2, \text{exp}(N_2, N_3) \Rightarrow \text{exp}(N_0, N_3), \text{pragma\ passive(}\text{Id}_1), \text{-passive(}\text{Id}_2).$$

This means that whenever a new exp constraint is created, only one test is generated for this rule, namely for a potential match with the rightmost exp at the lhs of this rule. The advent of token(+, ⋯) will never trigger this rule. It can observed\footnote{To prove this, one needs to argue in terms of a fairly detailed model of CHR’s execution model \cite{1}.} that the modified constraint solver produces exactly the same constraints as the original one (and even in the same order), the parts removed from the computation process are a lot of tests for applicability of rules anyhow destined to fail. We have not made a formal analysis of the time complexity for these modified parsers but tests for a variety of grammars indicate a linear or almost linear behaviour.

Another source of inefficiency is the potentially large number of constraints that pile up in the state; fewer final constraints will also make it easier to interpret the result of the parsing process. One way to reduce this is to apply CHR’s reduction rules instead of propagation rules, i.e., write “$\Leftarrow\Rightarrow$” instead of “$\Rightarrow$”. The effect is that the constraints matched on the lhs of the rule are removed from the constraint store and thus fewer parse trees will be recognized. Thus reduction rules should only be used for parts of a grammar known to be unambiguous. Alternatively, it can be seen as a method to make an ambiguous grammar unambiguous and a mixture of propagation and reduction rules can be used. Some degree of ambiguity, however, can be handled in a reduction rule by means of backtracking using disjunctions at the rhs of rule, cf. \cite{3}, or by launching all different hypothesis into the constraint store at the same time.

Since the position of tokens are explicit in the rules we can also let parsing depend on other symbols than the sequence being reduced. One example of this is to incorporate a look-ahead based on LR-items (see, e.g., \cite{6}) as in the following grammar for arithmetic expressions. Here we use CHR’s so-called simpagation
rules: Constraints matched to the left of the backslash stay in the constraint store and the other ones are removed; the test in front of the vertical bar is the a guard. We assume the text is followed by the terminal symbol `eof` and the following rule says that "exp + exp" is reduced provided the next input token is the specified list.

\[
\text{token}(R, N3,N4) \setminus \exp(N0,N1), \ \text{token}(+,N1,N2), \ \exp(N2,N3) \\
\implies \text{member}(R, [+,'\)','eof]) \ | \ \exp(N0,N3).
\]

The passive pragmas can be added as described provided that "right-most symbol" in the lhs of a rule is identified by means of the indices so that, in the rule above, the `token` in front of the backslash is the non-passive one and thus the one and only that can trigger the rule.

Together with the following rules (pragmas understood), we have a grammar for arithmetic expressions with traditional associativity and precedence.

\[
\text{token}(R,N3,N4) \setminus \exp(N0,N1), \ \text{token}(\ast,N1,N2), \ \exp(N2,N3) \\
\implies \text{member}(R, [\ast,+',\)','eof]) \ | \ \exp(N0,N3).
\]

\[
\text{token}(R,N3,N4) \setminus \exp(N0,N1), \ \text{token}(^,N1,N2), \ \exp(N2,N3) \\
\implies R \neq ^ \ | \ \exp(N0,N3).
\]

\[
\text{token}(\(',N0,N1), \ \exp(N1,N2), \ \text{token}(\)' ,N2,N3) \implies \exp(N0,N3).
\]

\[
\text{token}(\text{Int},N0,N1) \implies \text{integer}(\text{Int}) \ | \ \exp(N0,N1).
\]

As a result we achieve an efficient parser in which the constraint store is used effectively as a stack and the parser performs exactly the same steps and comparisons as a traditional LR(1) parser.

We conclude that time complexity is not a problem for CHR parsers and that flexibility is available for the grammar writer to consider symbols (not only terminals!) to the left and to right of the symbols reduced, to combine CHR’s different kinds of rules and pragmas with different effects, to add new tokens on the rhs (not shown), etc., etc. In addition, the parser may refer to constraints that represent other than purely syntactic hypothesis: this appears in the following.

### 4 Assumption Grammars and beyond

With CHR it is possible to let rules produce and consume arbitrary hypotheses. Consider the following sketch of two CHR grammar rules,

\[
\ldots \implies \ldots \ h(X) \ldots .
\]

\[
\ldots \ h(X) \ldots \implies \ldots .
\]

The first rule produces a hypothesis, say `h(a)`, extracted from the context in which the rule is applied and the second rule can be executed when such a hypothesis is present and the value `x=a` becomes available. Anaphora in natural language can be treated by passing hypotheses through the constraint store in this way.

Assumption grammars include specialized operators for managing such hypotheses and we show how they can be implemented and applied in CHR
grammars. In an assumption grammar, the expression $+h(a)$ asserts a linear hypothesis which can be used once in the following text by means of the expression $-h(a)$ (or $-h(X)$), called an expectation. Asserting the hypothesis by $+h(a)$ means that it can be used over and over again. We represent an assertion $+h(a)$ by a constraint $+(h, [a], n)$: the predicate symbol and argument list are split for technical reasons and $n$ indicates a position in the string where the hypothesis is supposed to be created. The two other operators are represented in analogous ways. Deviating slightly from the syntax of [12] (as to achieve a more symmetric notation), we introduce three new operators for “time-less” hypotheses, $=+$, $=-$, and $=*$, whose meanings are similar except that hypotheses can be used and consumed in any order; for these we can leave out the string index. The following simplification and simpagation rules provide an implementation in CHR.

\[
\begin{align*}
+(P,A) \>, \> -(P,B) & \iff \text{true} & \text{true} & \text{true} \\& \ A=B \ | \ \text{true}. \\
*(P,A) \> \ \& \> -(P,B) & \iff \text{true} & \text{true} & \text{true} \\& \ A=B \ | \ \text{true}. \\
+(P,A,Z1) \>, \> -(P,B,Z2) & \iff Z1 < Z2 \& \ A=B \ | \ \text{true}. \\
*(P,A,Z1) \> \ \& \> -(P,B,Z2) & \iff Z1 < Z2 \& \ A=B \ | \ \text{true}.
\end{align*}
\]

The explicit unification in the guard serves as test for unifiability as well as for porting the argument value from the asserted hypothesis (supposed to be ground) to its application.\footnote{CHR matches constraints to be processed by a common “instance of” condition, so that the rule $=+(P,A), =-(P,A) \iff \text{true}$ would apply in fewer cases than the corresponding one above.} Correct derivation in an assumption grammar requires that all expectations are matched by corresponding assertions in the end and an optional test all_consumed is available meaning that all linear hypotheses have been consumed; these and similar facilities are easily implemented by means of CHR’s auxiliary predicates.\footnote{E.g., all_consumed:- \+/ find_constraint(+(_,_,_),_), \\+/ find_constraint(=+(_,_,_),_),.}

However, the use of hypotheses introduces one technical problem in CHR, because a give parse tree has its specific set of hypotheses. Thus, with an ambiguous grammar and propagation rules we would mix up hypotheses corresponding to different trees. For the present we assume unambiguous grammars and use simplification rules. We give excerpts from a sample grammar inspired by [12] demonstrating anaphora and coordination. An occurrence of a proper name for some individual (“X” in the following rule) introduces a hypothesis that this individual can be referred to subsequently by a pronoun.

\[
\begin{align*}
\text{proper_name}(X, \text{Gender}, N1, N2) & \iff \\
\ast(\text{active_individual}, [X, \text{Gender}], N1), \text{np}(X, \text{Gender}, N1, N2).
\text{pronoun}(\text{Gender}, N1, N2) & \iff \\
\ast(\text{active_individual}, [X, \text{Gender}], N1), \text{np}(X, \text{Gender}, N1, N2).
\end{align*}
\]

Coordination arise in relation to ellipses as in “Mary likes and Martha hates Peter”. The object for the first sentence is implicit and shared with the second sentence. Simple and full sentences are described as follows.
The following two rules take care of coordination. Notice that the ellipsis is identified by a look-ahead for “and”; the second of two and’ed sentences offers its object to anyone missing its object.

\[ \text{token(and,N3,N4)} \setminus \text{np(Sub,\_),N1,N2), \text{verb(V,N2,N3)} \Rightarrow \text{=}-(\text{ref_object,}[[\text{Obj}]]) \Rightarrow \text{sentence(V-(Sub,Obj),N1,N3).} \]

\[ \text{sent(S1,N1,N2), token(and,N2,N3), sent(V2-(Sub2,Obj2),N3,N4) \Rightarrow \text{=}+(\text{ref_object,}[[\text{Obj2}]]) \Rightarrow \text{sent(S1+(V2-(Sub2,Obj2)), N1,N4).} \]

With these and a few other obvious rules, the analysis of “Mary likes Peter. She loves and Martha hates him.” yields the following semantic representation.

\[ \text{likes-(mary,peter) + loves-(mary,peter) + hates-(martha,peter)} \]

However, this example gives rise to some discussion of assumption grammars. First of all, if the sentence preceding “and” happens to be complete, the asserted hypothesis will not be used here but may interfere with the analysis of subsequent ellipses. To avoid this, the CHR rule can be refined so that it only asserts the hypothesis if there is need for one; replacing the unconditional assertion by the following piece of code will do.

\[ \text{find_constraint(=}-(\text{ref_object,}_,_)) \Rightarrow \text{=}+(\text{ref_object,}[[\text{Obj2}]]) \Rightarrow \text{true} \]

In general, we believe that a more detailed control of the scope of asserted hypothesis is needed than what is feasible with assertion grammars. The explicit string indices are useful for this as well as the low-level primitives of CHR and it seems that suggestions for any such “high-level” scoping mechanism can be implemented.

Another feature missing in assumption grammars is the selection of a best hypothesis for, say, resolving a pronoun, e.g., considering distances in the string or which hypothesis has been applied most often. We can sketch a rule as follows; the constraint before the backslash serves as a test that there are applicable hypotheses.

\[ \text{+(active_individual,[_\_Gender],N) \setminus pronoun(Gender,N1,N2) \Rightarrow N<N1 | select the best hypothesis of form +(active_individual,[X\_Gender],_) according to some criteria and remove it from the constraint store, np(X,Gender,N1,N2).} \]

If more hypotheses are feasible, they can be tested on backtracking. — We leave it to competent linguists to design such mechanisms. What we have indicated here is that CHR seems to provide a framework for implementing them.

\[ ^4 \text{A tree-like scoping provided by implications goals } \] does not seem sufficient as some hypotheses may be relevant from, say, position 10 to 25 and others from 20 to 30. In addition, some hypotheses may be temporarily overruled by others.
5 Abduction and integrity constraints

As several authors [11,7,18,20] have noticed, abduction is a useful way to conceive and to implement aspects of natural language interpretation. A deductive approach, as exercised in section 4, represents the meaning of a text by a complex structure attached to the start symbol and which has been synthesized from meanings of its constituents. By abduction, the meaning appear as assumptions generated in parallel with the syntactic analysis as they are needed, and integrity constraints can check dynamically that the collected set of hypothesis is consistent. Consider the following DCG rule.

\[ A \rightarrow B_1, \ldots, B_n, \{P\}. \]

Now the instance of a nonterminal should be understood as the presence of a good phrase, e.g., a true sentence or a noun phrase referring to an existing object, and the related instance of \( P \) is the precondition for the composition of good subphrases itself to be a good phrase. When formulating language interpretation as abduction, the unknown is a body of assumptions that entails the set of all such \( P \) instances that have been applied. The literature is rich of abduction procedures which can do this job, e.g., [10,13,14,21].

In [2] we have shown how abduction with integrity constraints can be expressed in CHR. In the following we illustrate how to integrate it with a CHR parser, however, without caring about the formal relation. A DCG rule as above is written as the following CHR grammar rule:

\[ B_1(N_0,N_1), \ldots, B_n(N_{n-1},N_n) \leftrightarrow P, A(N_0,N_n). \]

Applying it will introduce into the constraint store the instance of \( P \) that was necessary for the previous DCG rule to apply. The \texttt{active_individual(· · ·)} hypotheses generated in the example of section 4 can be seen as an part of abductive explanation why the text could have been sensibly and correctly uttered. Gender of an individual may be recognized from its proper name in a lexicon or deduced from context. Thus the following integrity constraint is relevant:

\[ \texttt{active_individual}(X,\text{masc}), \texttt{active_individual}(X,\text{fem}) \leftrightarrow \text{fail}. \]

Sentence meanings can be removed from the nonterminal and instead be launched into the constraint store:

\[ \text{np}(\text{Sub,}_-,N_1,N_2), \text{verb}(V,N_2,N_3), \text{np}(\text{Obj,}_-,N_3,N_4) \leftrightarrow \text{fact}(V,\text{Sub},\text{Obj}), \text{sent}(N_1,N_4). \]

Different anaphoric resolutions can be thinned out along the way by means of “semantic” integrity constraints such as:

\[ \text{fact}(\text{likes},X,Y), \text{fact}(\text{hates},X,Y) \leftrightarrow \text{fail}. \]
\[ \text{fact}(\text{loves},X,Y), \text{fact}(\text{hates},X,Y) \leftrightarrow \text{fail}. \]
\[ \text{fact}(\text{hates},X,X) \leftrightarrow \text{fail}. \]

\( ^5 \) This is likely to produce several instances of the same hypothesis but CHR has means to avoid this.
This will provide a correct interpretation of tricky combinations such as “Mary likes Martha. She hates her.”

Abduction provides also a way to work with negative hypotheses by means of explicit negation as expressed in the sketch of an integrity constraint, not $H$, $H \iff \text{fail}$. It means that anything can be asserted until the opposite has been proved.

We have indicated that CHR as grammar formalism seems capable of integrating abductive text interpretation which has several benefits over explicit synthesis of meanings. However, the principle we have illustrated still needs to be refined and its formal grounds to be established.

As we have described it, grammar rules have to be represented as simplification rules, otherwise different hypothesis sets for different parse trees will be mixed up. Thus alternatives can only be explored by backtracking in the rule bodies. However, it seems to be a matter of proper engineering to find ways to manage sets of alternative and mutually exclusive hypotheses in the same constraint store; weighted abduction [20] seems to fit into such a model or a more structured approach based on fuzzy logic could be used. Integrity constraints should also behave in a less rude way, by simple having wrong hypotheses to vanish instead of provoking failure and thus backtracking.

6 Conclusion and perspectives

What we have called CHR grammars relates to CHR the same way that DCGs relate to Prolog. Grammar rules are written in a systematic way as rules of the host language and can be used directly as a parser that inherits the computational characteristics of the underlying machinery. Where DCGs work top-down with backtracking, CHR grammars works bottom-up. In addition to provide an evaluation strategy better suited for parsing, especially of natural language, the CHR paradigm supports the use of dynamically generated hypotheses, e.g., for abduction or as in Assumption Grammars, that is extremely useful for natural language analysis.

The experiences we have reported here are indeed promising for the use of CHR as a grammatical formalism. It provides a high degree of flexibility and expressive power for language processing of which we believe to have exposed only a small portion.

The comparison with DCGs may suggest to add a layer of syntactic sugar to suppress arguments for syntactic indices and to introduce high-level devices to replace the different uses of them. Take the simplification rule for an arithmetic plus shown in section 3. By means of a suitable preprocessor, we may suggest to write it in the following nice way.

\[
\text{exp, [+], exp} \rightarrow ([+] ; [\text{'}]) \rightarrow \text{exp}.
\]

We prefer to keep the order of lhs and rhs of the rules to indicate their bottom-up nature and to let the choice of propagation and simplification rule be visible.
using symbols “\-\textarrow{->}” and “\textarrow{<->}”. As in DCG, curly brackets can be used to indicated code to be bypassed by the preprocessor, and notice that it is relevant to apply this at both sides of a CHR grammar rule. The “\textarrow{-}” marker indicates a reference to the right context of the sequence being reduced; an analogous “\textarrow{-\textbackslash}” marker can be used at the beginning of a rule to indicate references to the left context. To add \texttt{passive} pragmas to all but the leftmost grammar symbol at the lhs as described in section \ref{sec:passive}, a rule may be prefixed with an operator “\texttt{ruleLR}” or a global directive “\texttt{:- modeLR}.” can affect all rules. The LR mode should not be forced as it may affect the final result for CHR grammars using reduction rules.

Our investigation has also exposed interesting topics for future work: To study the possible relation between abduction and assumption grammars (perhaps as instances of a more general framework of hypothetical reasoning) and to design high-level facilities for controlling the scope of hypotheses. As we pointed out in section \ref{sec:future}, technical work is needed in order to achieve a full bottom-up and non-backtracking version of abduction. Plans for the near future include extraction of noun phrases to be used in a Danish ontology-based search systems which is developed in parallel with an implementation using traditional language processing tools. A grammar for a substantial subset of Danish is under consideration with contextual and perhaps some kind of semantic analysis.

\textbf{Acknowledgment:} This research is supported in part by the OntoQuery funded by the Danish Research Councils, and the IT-University of Copenhagen.

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