For-loops in Logic Programming

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Abstract: Logic programming has traditionally lacked devices for expressing iterative tasks. To overcome this problem, this paper proposes iterative goal formulas of the form $\land^x_L G$ where $G$ is a goal, $x$ is a variable, and $L$ is a list. $\land^x_L$ is called a parallel bounded quantifier. These goals allow us to specify the following task: iterate $G$ with $x$ ranging over all the elements of $L$.

keywords: for-loop, iteration, bounded quantifier, computability logic

1 Introduction

Logic programming has traditionally lacked mechanisms that permit some tasks to be iterated. This deficiency is an outcome of using a weak logic as the basis for logic programming. Lacking looping constructs, logic programming relies on recursion to perform iterative goal tasks. One of the disadvantages of this approach is that even simple iterative goal tasks are difficult to read, write and reason about. Also, iteration can be directly implemented much more efficiently than recursion.

To deal with this deficiency, our approach in this paper involves the direct enrichment of the underlying intuitionistic logic to a fragment of Computability Logic (CL) in [3, 4] to allow for iterative goals. A parallel iterative goal is of the form $\land^x_L G$ where $G$ is a goal, $x$ is a variable, and $L$ is a list. Executing this goal has the following intended semantics: iterate $G$ with $x$ ranging over all elements of the list $L$. All executions must succeed for executing $\land^x_L G$ to succeed.

An illustration of this facet is provided by the following definition of the relation which sequentially writes all the elements in a list:

$\text{write}\_\text{list}(L) : - \quad \text{write}("List : ") \land$

$(\land^x_L \text{write}(x)).$

which replaces the tedious logic program shown below:

$\text{write}\_\text{list}(L) : - \quad \text{write}("List : "),$

$\text{write}\_\text{list}1(L).$

$\text{write}\_\text{list}1([]).$

$\text{write}\_\text{list}1([X|T]) : - \quad \text{write}(X),$

$\text{write}\_\text{list}1(T).$
The body of the new definition above contains an iterative goal. As a particular example, solving the query `write_list([1, 2, 3])` would result in solving the goal $\land_{[1,2,3]}$, after writing `List :`. The given goal will succeed after writing 1, 2, 3 in sequence.

As seen from the example above, iterative goals can be used to perform looping tasks. This paper proposes Prolog`forloop`, an extension of Prolog with iterative operators in goal formulas.

There are some previous works [1, 2] that have advocated the use of bounded quantifiers. Although their motivation is similar to ours, the difference is that their approach stays within the framework of Prolog. In other words, bounded quantifiers are just syntactic sugars and must be transformed to lengthy Prolog codes before execution.

Our approach overcomes this inefficiency: bounded quantifiers are now legal and can be implemented in a direct, efficient way, i.e., without translation to Prolog.

In this paper we present the syntax and semantics of this extended language, show some examples of its use.

The remainder of this paper is structured as follows. We describe Prolog`forloop` based on a first-order Horn clauses with bounded quantifiers in the next section. In Section 3, we present some examples. Section 4 concludes the paper.

2 The Language

The language is a version of Horn clauses with iterative goals. It is described by $G$- and $D$-formulas given by the syntax rules below:

$$
G ::= A \mid G \land G \mid \exists x \ G \mid G \land \land_{x} G \\
D ::= A \mid G \supset A \mid \forall x \ D \mid D \land D
$$

In the rules above, $x$ represents a variable, $L$ represents a list of terms, and $A$ represents an atomic formula. A $D$-formula is called a Horn clause with iterative goals.

In the transition system to be considered, $G$-formulas will function as queries and a set of $D$-formulas will constitute a set of instructions. For this reason, we refer to a $G$-formula as a query, to a set of $D$-formulas as an instruction set.

We will present an operational semantics for this language as inference rules. To be specific, we encode such inference rules as theories in the (higher-order) logic of task, i.e., a simple variant of Computability Logic [3]. Below the expression $A$ sand $B$ denotes a sequential conjunction of the task $A$ and the task $B$ and the expression $A$ pand $B$ denotes a parallel conjunction of the task $A$ and the task $B$.

These rules in fact depend on the top-level constructor in the expression, a property known as uniform provability[7, 8].

**Definition 1.** Let $G$ be a goal and let $\mathcal{P}$ be a finite set of instructions. Then the notion of executing $\langle \mathcal{P}, G \rangle$ – executing $G$ relative to $\mathcal{P}$ – is defined as follows:

1. $\text{exec}(\mathcal{P}, A)$ if $A$ is identical to an instance of a program clause in $\mathcal{P}$. 

exec(P, A) if (an instance of a program clause in P is of the form G_1 \supset A) \textit{pand} exec(P, G_1).

exec(P, G_1 \land G_2) if exec(P, G_1) \textit{pand} exec(P, G_2). Thus, the two goal tasks must be done in parallel and both tasks must succeed for the current task to succeed.

exec(P, \exists x G_1) if (select the true term t) \textit{sand} exec(P, [t/x]G_1). Typically, selecting the true term can be achieved via the unification process.

exec(P, \land^{|x|}_x G). The current execution terminates with a success.

exec(P, \land_{x}^{[a_1,...,a_n]} G) if exec(P, [a_1/x]G) \textit{pand} exec(P, \land_{x}^{[a_2,...,a_n]} G).

In the above rules, the symbols \( \land^L_x \) provides iterations: they allow for the repeated conjunctive execution of the instructions. We plan to investigate whether this semantics is sound and complete with respect to CL.

An alternative yet tedious way to giving semantics of our language is by transformation to plain logic programming. For example, our loop construct \( \land^L_x \) can be defined by introducing a recursive auxiliary predicate such as \texttt{write_list1} in Section 1. This method is discussed in detail in [2].

3  Examples

An example is provided by the following “factorial” program.

\[
\text{fact}(0, 1). \textit{\% base case} \\
\text{fact}(X + 1, XY + Y) : - \text{fact}(X, Y).
\]

Our language in Section 2 permits iterative goals. An example of this construct is provided by the program which does the following tasks: output 10!, 11!, 12!, 13! sequentially:

\[
\text{query1 :} \\
\land_{N}^{[10,11,12,13]} \textit{\% for i = 10 to 13 begin} \\
(fact(N, O)) \land \\
write(N) \land write(\textit{\textquoteleft factorial is :\textquoteleft}) \land \\
write(O)) \textit{\% for end}
\]

For example, consider a goal \texttt{query1}. Solving this goal has the effect of executing \texttt{query1} with respect to the factorial program for four times.

Our language in Section 2 permits variables to appear in the list in iterative goals. These variables can be used only for controlling iteration and must be instantiated at run-time.
An example of this construct is provided by the program which does the following iterative tasks: read a number $N$ from the user, and then repeatedly output the factorials of the numbers from 1 to $N$.

\[
\text{query2 ::}
\]
\[
\text{(read}(N)\land
\land_{x=1}^{[1..N]} \% \text{ for } x=1 \text{ to } N \text{ begin}
\]
\[
\text{(fact}(x,O)\land
\text{write}(x) \land \text{write('factorial is:')}\land
\text{write}(O)) \% \text{ for end}
\]

In the above, note that $[1..N]$ is a shorthand notation for $[1, 2, \ldots, N]$.

4 Conclusion

In this paper, we have considered an extension to logic programming with iterations in goals. This extension allows goals of the form $\land_x^L G$ where $G$ is a goal, $x$ is a variable and $L$ is a list of terms. These goals are particularly useful for the bounded looping executions of instructions, making logic programming more concise, more readable, and more friendly to imperative programmers.

Although iterative goals do provide a significant gain in expressive elegance, some tasks — with dynamic termination conditions — cannot be expressed at all using them. We plan to look at some variations [2] such as the \textit{fromto} statements in the future to improve expressibility.

Regarding implementing our language, the handling of bounded quantifications does not pose any major complications. The treatment of a goal of the form $G_1 \land G_2$ that is indicated by the operational semantics does not forbid $G_1$ and $G_2$ to be processed sequentially, as is done in most Prolog implementations.

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