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Modularization and Abstraction in Logic Programming

-extended abstract-

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In knowledge information processing, structuring of knowledege and algorithm is one of the key issues. The goal of this work is to introduce the concepts and mechanisms of abstraction, modularization and parameterization into logic programming which is one of the preliminary steps toward the kernel langage of the fifth generation computer systems.

1. Introduction

To break the complexity barrier of software, modularization seems to be one of the most effective means.

The idea of "program modularization through abstraction" [Dijkstra, Hoare, Dahl 70] has seen its success in the scene of conventional imperative (von Neuman style) programming. This idea has promoted the development of languages such as CLU [Liskov 79] and Iota [Nakajima 80] whose primal modularization mechanisms are the defining facilities of abstract data types.

On the other hand, little work has been done to introduce modularization mechanisms in the design of logic programming languages. (An exception is Mprolg and its software support system LDM [Farkas 82], but they seem to limit themselves to providing some grouping facilities in their language.) Based on our experiences in writing large software in Prolog, we assert that introduction of modularization by way of abstraction mechanisms especially data abstraction is highly useful or even necessary in logic programming.

A logic programming language called Himiko, which we are currently designing, provides data abstraction and modularization mechanisms as language constructs.

2. Data types, Modules

HIMIKO is based on a many-sorted logic. Namely HIMIKO includes data type concepts, where a type is a collection of terms which are generated in an explicitly specified manner. This mechanism can reduce the possibility of errors which are caused by mismatching between term structures during unification procedures and enhance readability of programs at the cost of some inflexibilities. Note that we assume that the language is to be embedded in an integrated programming system which will include powerful programming support and validation facilities and lighten the burden of the programmers due to the introduction of strict programming disciplines.

There are two kinds of data types in Himiko; types and patterns. Types correspond to abstract data types whose term structures are encapuslated into their defining modules and to which access is possible only through a set of "menu"ed operations (Section 3). On the other hand, patterns are those whose term structures are shown to outside of the modules. Both types and patterns are parametrized with respect to data types. For instrans the type of queues of arbitrary elements are given in Himiko by a type QUEUE(T) where T is a data type parameter. By passing an actual type or pattern to T, one can get a type of queues consisting of elements of a definite data type. We do not, however, get into details of patterns or type-parametrization in this version of the report.

A program in HIMIKO is written as a hierarchy of modules. Semantically a module defines a chunk of theory and syntactically it consists of interface that declares the relations and data types as well as realization that gives the logic programs. The syntax for modules is designed under the assumption that a modular programming system will be provided for HIMIKO with which construction and management of modules are supported by module data base facilities.

A module is the minimal unit to which abstraction and parameterization (as described below) are applied.

3. Abstraction

The notion of data abstraction is based on the view that a data type is characterized by a set of operations which are basic on the type and that access to any object of the type is allowed only through those operations. A module in HIMIKO encapuslates the types that it defines. Namely the concrete structure of the terms which form the type is not visible from the outer modules. Suppose a modole M define a type tt and relations q and r on tt. The terms of the type tt are supposed to be generated only by q and r and therefore satisfy a certain invariance condition whose preservation is often essetial for algorithm correctness. If an object of tt was accessed from another module N directly without referring to q or r, the condition would be violated to result in a logical error in the program. Therefore the only legal access to objects of tt from N should be through q and r. Moreover in the text of N the arguments of q and r of type tt can appear as variables, i.e. q(x,y) ,not q(f(2,x),f(4,y)). All necessary unification procedures to terms of tt are restricted to M.

A module in Himiko consists of an interface part and a realization part (see Figure A). An interface part specifies the names and functionality (argument types) of the relations which are defined by the module and which are accessible from outside the module. ri, r2,... in Figure A are such relations. If abstract data types are defined by the module, their names are given in the interface part and the names of the relations which characterize the abstract data types are also given in the interface part together with their functionality. In Figure A, n1, n2, n3 are the names of the abstract data types which are defined by the module.

The realization part of a module defines the relations whose names are given in the corresponding interface part. (Relations are defined in the form of Horn clause.) To define the relations, the realization part may contain the definitions of relations that are not named in the interface part. Such relations cannot be used outside the module. When names of abstract data types are given in the interface part, their representations must be specified as "term" structures in the corresponding realization part. The equations that follow repr in Figure A specify such representations.

Note that a group of abstract data types are characterized by mutual "relations" among types in the group. Thus, a module in Himiko may define more than one abstract data type simultaneously, which is different from the corresponding notions in Iota and Clu. A module in Himiko may define a collection of relations which are utilized to accomplish a single task, or a collection of relations which are packaged as a unit. In such cases, only the relations whose names are given in the interface part can be accessible (or called) from outside the module.

```
module

    interface
        type  <n1>, <n2>, <n3>

        rel
            r1(<n1>, <n2>, <n3>)
            r2(<n1>, <integer>, <n2>)
              .
              .
              .

    realization
        repr
             <n1> =    ...term structure...

             <n2> =    ...term structure...

             <n3> =    ...term structure...

        clause
             r1(....).
             r1(....) :- s1(...), s2(...).

             r2(....).
             r2(....) :- s3(...), s4(...).
             r2(....) :- s5(...), r2(...).
              .
              .
              .

end-of-module
```

Figure A. Module Structure

To show how programs in Himiko are structured through the notion of modules, we consider (a fragment of) the Himiko programs depicted in Figure C,D,E which implement a simplified version of a T-Prolog interpreter. (T-Prolog is a logic-based programming language for simulation.) The interpreter takes a goal list as input and a final state as output, and it simulates events described in the goal list. The module for the interpreter (Figure E) defines a relation "execute" which is defined in terms of a relation "execute1". The definitions of these relations are given in the realization part. This module uses a module which defines an abstract data type "state". (See Figure D.) This type is an abstraction of the state of the simulated world. The relations (or operations) that are basic to this type are those for creating a state, recording state changes, simulated actions of processes and so on. The definitions for "execute" and "execute1" are described in terms of the relations defined by the state-process.

As specified in the realization part, the abstract data type "state" is represented as a term structure whose functor name is 'state'. This term consists of three subterms which correspond to a queue for waiting processes, a queue for blocked processes and an identifier for the currently active process. The subterms corresponding to queues are constructed from variables of an abstract data type queue. The definitions of relations (operations) basic to queues and the data representation for the type queue are described in the module depicted in Figure E. Note that this module contains two realization parts, one describing the list implementation of a queue, the other the d-list (difference list) implementation of a queue. (The hierarchy of the modules for the interpreter programs is illustrated in Figure B.)

```
                    ---------------
                    | interpreter |
                    ---------------


                  -----------------
                  | state-process |
                  -----------------


                       ---------
                       | queue |
                       ---------


 - - - - - - - - - - - - -     - - - - - - - - - - - - - - -
 | list implementation |       |  d-list implementation   |
 - - - - - - - - - - - - -     - - - - - - - - - - - - - - -
```

Figure B

An interesting point in our language design for program modules is that term structures are allowed in definitions of relations. Namely, the term strauctures also plays a role of basic type constructors such as list and thus substerms (which correspond to componemts of data structures) are extracted or modified by unification procedures, preserving a powerful feature of the Prolog type logic programming. (This, in turn, implies that some of arguments for a relation do not have to be typed.)

Note that [Kowalski 79] introduced the idea of separation of data structure from programs to increase their readability and reliability, but he did not extend his idea to design a language which supports modularity.

```
module queue-module
  interface
    type <queue>

    rel  create-q(<queue>)          ;create an empty queue.
         en-q(<item>,<queue>,<queue>)
                    ;put an <item> at the end of queue.
         de-q(<item>,<queue>,<queue>)
                               ;delete the item at the top of the queue

  realization(1)
    repr
          <queue> = <list>     ;a queue is implemented as a usual list.

    clause   create-q([]).
             en-q(X,Q,Q1) :-  append(Q,[X],Q1).
             de-q([],[],[]).
             de-q(X,[X|Q],Q).


  relaization(2)
    repr
         <queue> = d(<list>,<list>)
                          ;a queue is implemented as a d-list.

    clause   create-q(d(Q,Q)).
             en-q(X,d(Q,[X|Q1]),d(Q,Q1)).
             de-q(X,d([X|Q],Q1),d(Q,Q1)).

end-of-module
```

Figure C

```
module state-process-module

    rel  create-state(<state>)          ;create an initial state.
         get-active-process(<process-id>,<state>)
                                 ;get the currently active process.
         new-active-process(<process-id>,<state>,<state>)
                                 ;make the <process-id> active
         make-process-await(<process>,<state>,<state>)
         make-process-blocked(<process>,<condition>,<state>,<state>)
         awake-waiting-process(<process>,<state>,<state>)
            .....
            .....

  realization
    repr
      <state> = state(waiting(<queue>),
                      blocked(<queue>),
                      active(<process-id>))

    clause
         create-state(state(waiting(Q1),blocked(Q2),active(self))
                   :-create-q(Q1),create-q(Q2).
         get-active-process(ID,state(_,_,active(ID))).
         new-active-process(ID,state(W,B,_),state(W,B,active(ID))).
         make-process-await((PGL,ID),
                               state(waiting(QW),BPQ,AP),
                               state(waiting(QW1),BPQ,AP))
                   :- en-q((PGL,ID),QW,QW1).
         make-process-blocked((PGL,ID),C,state(WPQ,blocked(QB),AP),
                                        state(WPQ,blocked(QB1),AP))
                   :- en-q((PGL,C,ID),QB,QB1).
         awake-waiting-process((PGL,ID),
                                  state(waiting(QW), BPQ,AP),
                                  state(waiting(QW1),BPQ,AP))
                   :- de-q((PGL,ID),QW,QW1).
           .....
           .....
end-of-module
```

Figure D

```
module interpreter

  interface
    rel  execute(<<goal-list>, <state>)

        ; <goal-lis> is a raw term being represented as:
        ;  <goal-lis> = nil ¦ (<goal>,<goal-list>)
        ;  <goal> = new(<goal-list>,<process-id>)
        ;          ¦ wait(<condition>) ¦ ...

  end

  realization
    clause  execute(GL,FS)   ;FS stands for the final state.
                 :- create-state(IS),execute1(GL,IS,FS).
                                  ;IS gets an initial state.
        execute1((new(PGL,ID),GL),S1,S2)
                ;if the head of the goal list is the form new(*,*).
                 :- get-active-process(AP,S1),
                    make-process-await((GL,AP),S1,S3),
                    new-active-process(ID,S3,S4),
                    !, execute(PGL,S4,S2).

         execute1((wait(C),GL),S1,S2)
                 :- (C,execute1(GL,S1,S2))
                            ;if a condition C holds
                            ;then execute1(...)
                   or
                   get-active-process(AP,S1),
                   make-process-blocked((GL,AP),C,S1,S3),
                   !, call-sv(S3,S2).

         call-sv(S1,S2)
                 :-     ...     ,activate-waiting-process(S5,S2).

         activate-waiting-process(S1,S2)
                 :- awake-waiting-process((GL,ID),S1,S3),
                 new-active-process(ID,S3,S4),
                 !,execute1(GL,S4,S2).

              ......
              ......

end-of-module
```

Figure E

4. Logical viewing of terms

In logic programming all data structures are terms and procedures on them are given by unification mechanisms. Often a single data object can be viewed as more than one term structures on which different unification procedures are conveniently applied. For instance we have a string of characters "abc...k" which actually is represented as a list of characters:
cons(a, cons(b, ...(cons(k, nil))..).
On the other hand it is convenient to regard it as a page which is a sequence of lines where a line is a sequence of characters with a certain ending character. Namely

```
    line(k1, line(k2, line(....))..)
```

is another view with each ki standing for a line.

The transformation between those two term structures is given by the following Prolog-like program.

specification.

```
<PAGE1> = cons(eop,nil) ¦ cons(<CHAR1>, <PAGE1>)
<PAGE2> = cons(eop,nil) ¦ line(<LINE>, <PAGE2>)
<LINE>  = cons(eol,nil) ¦ char(<CHAR2>, <LINE>)
<CHAR1> = <CHAR2> ¦ eol
```

transformation.

```
trans(cons(eop,nil),cons(eop,nil)).
trans(cons(eol,PAGE1),line(cons(eol,nil),PAGE2))
    :- trans(PAGE1,PAGE2).
trans(cons(X,PAGE1),line(char(X,LINE),PAGE2))
    :- trans(PAGE1,line(LINE,PAGE2)).
```

HIMIKO utilizes such transformation rules to conduct virtual unification, that is, to unify an abstract term to an actual term. Most cases it is not necessary to transform the entire structure at a time but to perform only part of transformation at the time of the unification procedure. The lazy evaluation technique (e.g. by [Clark 81]) can be well embedded in HIMIKO to meet this goal.

5. Optimization

Modularization often introduces some inefficiency into programs at the cost of getting them well structured. Let us consider another example of an abstract data type representing a Rubik cube. Figure F shows a rule to manipulate the cube, which is written using directly the following concrete representation of the cube:

```
cube(front([F1,F2, ... ,F9]),
      back([B1,B2, ... ,B9]),
     lside([L1,L2, ... ,L9]),
     rside([R1,R2, ... ,R9]),
       top([T1,T2, ... ,T9]),
    bottom([O1,O2, ... ,O9])).
```

```
prod_rule(move_to_front_north:
         [X = cube(front([FC|_]),
                   back([_,_,TC|_])
                   _,
                   _,
                   top([TC,_,FC|_]),
                   _),
          found(X)]
          =>
            [apply([l_up,b_ccw,l_down,t_right],X,Y),
             replace(X,Y),
             print_cube_change(X,Y)]).
```

Figure F. A Rubik cube rule written using a concrete representation.

```
a part of upper module

  prod_rule(move_to_front_north:
           [a_cube(X),
            color(front:center of X, FC),
            color(back:north of X,   TC),
            color(top:center of X,   TC),
            color(top:north of X,    FC),
            found(X)]
            =>
              [apply([l_up,b_ccw,l_down,t_right],X,Y),
               ...]).
lower module
  module cube
    interface
      type <cube>

      rel  a_cube(<cube>)
               color(<face>:<position> of <cube>, <color>)

    realization
      repr
         <cube> = vector(vector(<F1>,<F2>, ... ,<F9>),
                         vector(<B1>,<B2>, ... ,<B9>),
                         vector(<L1>,<L2>, ... ,<L9>),
                         vector(<R1>,<R2>, ... ,<R9>),
                         vector(<T1>,<T2>, ... ,<T9>),
                         vector(<O1>,<O2>, ... ,<O9>))

      clause a_cube(vector(vector(_,_,_,_,_,_,_,_,_),
                           vector(_,_,_,_,_,_,_,_,_),
                           vector(_,_,_,_,_,_,_,_,_),
                           vector(_,_,_,_,_,_,_,_,_),
                           vector(_,_,_,_,_,_,_,_,_),
                           vector(_,_,_,_,_,_,_,_,_))).

        color(front:Position of vector(F,_,_,_,_,_), C)
                :- p_color(Position, F, C).

        color(back:Position of vector(_,B,_,_,_,_), C)
                :_ p_color(Position, B, C).

                        ...

        p_color(center, vector(C,_,_,_,_,_,_,_,_), C).

        p_color(north_west, vector(_,C,_,_,_,_,_,_,_), C).

                        ...

end of module
```

Figure G. A modularized version of a part of the Rubik cube program.

The modularized version of the rule as well as the lower realization module for the abstract data "cube" is show in Figure G.

Here, the single procedure call "X = cube(front([FC¦_]), back([_,_,TC¦_]), _, _, top([TC,_,FC¦_]),_,)" in Figure F is divided into four calls and makes the program inefficient. To avoid this defect, we use partial evaluation technique. If we partly perform the program in advance to the actual run, we can obtain the value of X in a_cube(X), which will result to:

```
X = vector(vector(FC,_,_,_,_,_,_,_,_),
           vector(_,_,TC,_,_,_,_,_,_),
           _,
           _,
           vector(TC,_,FC,_,_,_,_,_,_),
           _)
```

This is equivalent to the literal in the original program (in Figure F) directly manipulating the actual representation in Figure G.

Reference

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