

Logic Programming

Efficient Prolog. I/O

October 2018

The procedural aspect of Prolog

- ▶ While Prolog is described as a declarative language, one can see Prolog clauses from a procedural point of view:

```
in(X, usa):-  
    in(X, mississippi).
```

The above can be seen:

- ▶ from a declarative point of view: “X is in the USA if X is in Mississippi”,
 - ▶ from a procedural point of view: “To prove that X is in the USA, prove X is in Mississippi”, or “To find X in USA, (it is sufficient to) find them in Mississippi”.
- ▶ Procedural programming languages can also contain declarative aspects. Something like

```
x = y + z ;
```

can be read

- ▶ declaratively, as the equation $x = y + z$,
- ▶ procedurally: load y, load z, store x.

The need to understand the procedural/declarative aspects

- ▶ The declarative/procedural aspects are not “symmetrical”: there are situations where one not understanding one aspect can lead to problems.
- ▶ For procedural programs: $A = (B + C) + D$ and $A = B + (C + D)$ appear to have equivalent declarative readings but:
 - ▶ imagine the biggest number that can be represented is 1000,
 - ▶ then for $B = 501$, $C = 501$, $D = -3$, the two expressions yield totally different results!
- ▶ The same can happen in Prolog. Declaratively, the following is correct:

```
ancestor(A, C):-  
    ancestor(A, B),  
    ancestor(B, C).
```

However, ignoring its procedural meaning, this can lead to infinite loops (when B and C are both unknown).

- ▶ The task of a Prolog programmer is to build a model of the problem and to represent it in Prolog.
- ▶ Knowledge about this model can improve performance significantly.
?–horse(X), gray(X). will find the answer much faster than
?–gray(X), horse(X). in a model with 1000 gray objects and 10 horses.
- ▶ Narrowing the search can be even more subtle:

```
set_equivalent(L1, L2):–  
    permute(L1, L2).
```

i.e. to find whether two lists are set-equivalent it is enough to see whether they are permutations of each other. But for N element lists, there are $N!$ permutations (e.g. for 20 elements, 2.4×10^{18} possible permutations).

- ▶ Now considering a faster program:

```
set_equivalent(L1, L2):—  
    sort(L1, L3),  
    sort(L2, L3).
```

i.e. two lists are set equivalent if their sorted versions are the same. And sorting can be done in $N\log N$ steps (e.g. approx 86 steps for 20 element lists).

- ▶ When patterns are involved, unification can do some of the work that the programmer may have to do.
- ▶ E.g. consider variants the predicate that detects lists with 3 elements:



```
has_3_elements(X):-  
    length(X, N),  
    N = 3.
```



```
has_3_elements([_, _, _]).
```

- ▶ Also consider the predicate for swapping the first two elements from a list:

```
swap_first_2([A, B| Rest], [B, A| Rest]).
```

Letting unification work saves having to go through the whole list.

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- ▶ Comparison of atoms can be performed very fast because of tokenization.
- ▶ For example `a \= b` and `aaaaaaaaa \= aaaaaaab` can both be done in the same time, without having to “parse” the whole atom names.

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- ▶ For recursive procedures the continuation and backtracking point have to be remembered for each of the recursive calls.
- ▶ This may lead to large memory requirements

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- ▶ They are much more efficient than the non-tail recursive variants.
- ▶ The following is tail recursive:

```
test1(N):- write(N), nl, NewN is N+1, test1(NewN).
```

In the above write writes (prints) the argument on the console and succeeds, nl moves on a new line and succeeds. The predicate will print natural numbers on the console until the resources run out (memory or number representations limit).

- ▶ The following is not tail recursive (it has a continuation):

```
test2 (N):- write (N), nl, NewN is N+1,  
           test2 (NewN), nl.
```

When running this, it will run out of memory relatively soon.

- ▶ The following is not tail recursive (it has a backtracking point):

```
test3 (N):- write (N), nl, NewN is N+1,  
           test3 (NewN).  
test3 (N):- N<0.
```

- ▶ The following is tail recursive (the alternative clause comes before the recursive clause so there is no backtracking point for the recursive call):

```
test3a (N):- N<0.  
test3a (N):- write (N), nl, NewN is N+1,  
            test3a (NewN).
```

- ▶ The following is not tail recursive (it has alternatives for predicates in the recursive clause preceding the recursive call, so backtracking may be necessary):

```
test4(N):- write(N), nl, m(N, NewN),  
           test4(NewN).
```

```
m(N, NewN):- N >= 0, NewN is N + 1.
```

```
m(N, NewN):- N < 0, NewN is (-1)*N.
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Making recursive predicates tail recursive

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- ▶ If a predicate is not tail recursive because it has backtracking points, then it can be made so by using the cut before the recursive call.
- ▶ The following are now tail recursive:

```
test5(N):- write(N), nl, NewN is N+1,!,  
           test5(NewN).
```

```
test5(N):- N<0.
```

```
test6(N):- write(N), nl, m(N, NewN), !,  
           test6(NewN).
```

```
m(N, NewN):- N >= 0, NewN is N + 1.
```

```
m(N, NewN):- N < 0, NewN is (-1)*N.
```

- ▶ Note that tail recursion can be indirect. The following is tail recursive:

```
test7(N):- write(N), nl, test7a(N).  
test7a(N):- NewN is N+1, test7(NewN).
```

In the above we have mutual recursion, but note that test7a is just used to rename part of the test7 predicate.

Summary: tail recursion

- ▶ In Prolog, tail recursion exists when:
 - ▶ the recursive call is the last subgoal in the clause,
 - ▶ there are no untried alternative clauses,
 - ▶ there are no untried alternatives for any subgoal preceding the recursive call in the same clause.

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$d(e).$

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- ▶ These indices will be stored as a hash table or something similar for fast access.
- ▶ Therefore, Prolog will find $d(f)$ directly.

- ▶ Using indexing can make predicates be tail recursive when they would not be:

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test8(0):- write(' Still going '), nl, test8(0).  
test8(-1).
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The second clause is not an alternative to the first because of indexing.

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- ▶ Note, however, that indexing works only when the first argument of the predicate is instantiated.

- ▶ Consider some built-in predicates in Prolog, as presented in the help section of the program:

`append(?List1 , ?List2 , ?List3)`

Succeeds when List3 unifies with the concatenation of List1 and List2. The predicate can be used with any instantiation pattern (even three variables).

`-Number is +Expr [ISO]`

True if Number has successfully been unified with the number Expr evaluates to. If Expr evaluates to a float that can be represented using an integer (i.e, the value is integer and within the range that can be described by Prolog's integer representation), Expr is unified with the integer value.

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 - @ is used by some programmers to indicate that the argument contains variables that must not be instantiated.

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- ▶ There are two styles of I/O in Prolog:
 - ▶ Edinburg style I/O is the legacy style, still supported by Prolog implementations. It is relatively simple to use but has some limitations.
 - ▶ ISO I/O is the standard style, supported by all Prolog implementations.
- ▶ There are some overlaps between the two styles.

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```
?- write(X).  
_G243  
true.
```

```
?- write("some str").  
[115, 111, 109, 101, 32, 115, 116, 114]  
true.
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- ▶ Note that Prolog displays the internal representation of terms. In particular, the internal representation of variables.

Reading terms

- ▶ The predicate `read` accepts any Prolog term from the keyboard (typed in Prolog syntax, followed by the period).

```
?- read(X).  
 |: hello.  
 X = hello.
```

```
?- read(X).  
 |: 'hello there'.  
 X = 'hello there'.
```

```
?- read(X).  
 |: hello there.  
 ERROR: Stream user_input:0:37  
 Syntax error: Operator expected
```



```
?- read(hello).  
 |: hello.  
true.
```

```
?- read(hello).  
 |: bye.  
false.
```

```
?- read(X).  
 |: mother(Y, ada).  
X = mother(_G288, ada).
```

- ▶ The read predicate succeeds if its argument can be unified with the term given by the user (if this is a term). The examples above illustrate several possible uses and situations.

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- ▶ When a file is opened, Prolog will keep track of the position of the “cursor” in that file.

- ▶ One can switch between several open files:

```
?- see('aaaa'),  
   read(X1),  
   see('bbbb'),  
   read(X2),  
   see('cccc'),  
   read(X3),  
   seen.
```

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- ▶ Several files can be opened and written into:

```
?- tell('aaa'),  
   write('first line of aaa'), nl,  
   tell('bbb'),  
   write('first line of bbb'), nl,  
   tell('ccc'),  
   write('first line of ccc'), nl,  
   told.
```

Character level I/O

- ▶ The predicate `put` writes one character (integer representing the ASCII code corresponding to the character).

```
?- put(42).
```

```
*
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true.
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- ▶ The predicate `get` reads one character from the default input (console).

```
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```

```
|    %
```

```
X = 37.
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X = 37.
```

- ▶ In SWI Prolog, `put` can also handle nonprinting characters:

```
?- write(hello), put(8), write(bye).  
hellbye  
true.
```

Complete Information: SWI-Prolog Manual

- ▶ For exact details of the Edinburgh style I/O predicates in SWI Prolog, consult [Wielemaker, 2008] (also available in SWI Prolog by calling `? - help.`).

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 - ▶ Open and close streams in different modes.
 - ▶ Inspecting the status of a stream, as well as other information.
 - ▶ Reading/writing is done in streams.
- ▶ There are two special streams that are always open: `user_input` and `user_output`.

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- ▶ `alias(Atom)` – a name (atom) for the stream,
- ▶ **action for reading past the end of the line: `eof_action(error)` – raise an error condition, `eof_action eof_code` – return an error code, `eof_action(reset)` – to examine the file again (in case it was updated e.g. by another concurrent process).**

► Example:

```
test:-  
open('file.txt', read, MyStream, [type(text)]),  
read_term(MyStream, Term, [quoted(true)]),  
close(MyStream), write(Term).
```

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- ▶ `close(Stream)` is the version without options.

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- ▶ The predicate `close(Stream, Options)` closes `Stream` with `Options`.
- ▶ `close(Stream)` is the version without options.
- ▶ Options include `force(false)` (default) and `force(true)` - even if there is an error (e.g. the file was on a removable storage device which was removed), the file is considered closed, without raising an error.

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- ▶ **Example:**

```
?- stream_property(user_input, mode(What)).  
What = read.
```

Reading terms

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- ▶ Read about the Options in the documentation [Wielemaker, 2008].
- ▶ The following example illustrates the use of `variable_names`, `variables`, `singletons`:

```
?- read_term(Term, [variable_names(Vars),
  singletons(S), variables(List)]).
|      f(X, X, Y, Z).
Term = f(_G359, _G359, _G361, _G362),
Vars = ['X'=_G359, 'Y'=_G361, 'Z'=_G362],
S = ['Y'=_G361, 'Z'=_G362],
List = [_G359, _G361, _G362].
```

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- ▶ For options, other predicates for writing terms, consult the documentation.

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- ▶ Consult the documentation for the details of the syntax.

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 - ▶ the **associativity**: e.g. is $8/2/2$ $(8/2)/2$ or is it $8/(2/2)$?
 - ▶ **Note that logic predicates (i.e. those expressions that evaluate to “true” or “false” are not associative in general). Consider: $3 = 4 = 3$, and suppose it were left associative, then $(3 = 4) = 3$ evaluates to “false” = 3, which changes the type of the arguments.**

Operator syntax specifiers

| Specifier | Meaning |
|------------------|---|
| fx | Prefix, not associative. |
| fy | Prefix, right-associative. |
| xf | Postfix, not associative. |
| yf | Postfix, left-associative. |
| xfx | Infix, not associative (like =). |
| xfy | Infix, right associative (like comma in compound goals) |
| yfx | Infix, left associative (like +). |

Commonly predefined Prolog operators

| Priority | Specifier | Operators |
|----------|-----------|--|
| 1200 | xfx | <code>:-</code> |
| 1200 | fx | <code>:- ?-</code> |
| 1100 | xfx | <code>;</code> |
| 1050 | xfy | <code>-></code> |
| 1000 | xfy | <code>,</code> |
| 900 | fy | <code>not</code> |
| 700 | xfx | <code>= \= == \== @< is ==<</code> |
| 500 | yfx | <code>+ -</code> |
| 400 | yfx | <code>* / // mod</code> |
| 200 | xfy | <code>^</code> |
| 200 | fy | <code>-</code> |

Example

`%note the syntax of declaring the new operator:`

```
:- op(100, xfx, is_father_of).
```

```
    michael is_father_of kathy.
```

```
X is_father_of Y :- male(X), parent(X, Y).
```

```
?- X is_father_of kathy.
```

```
X = michael .
```

- ▶ Read: the paper [Covington, 1989, Covington et al., 1997].
- ▶ Read: Section 6.6, of [Covington et al., 1997].
- ▶ Read: Sections 2.2, 2.3, 2.6, 2.10, 2.12, A.7 of [Covington et al., 1997].
- ▶ Try out the examples in Prolog.



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