Prolog use cases *other than* genealogy (Part I/II)

Ralf Lämmel
Software Languages Team, Koblenz

https://developers.svn.sourceforge.net/svnroot/developers/repository/prolog-crash-course/

What’s Prolog?

- A language based on ***logic*** (say, Hoare clauses).
- A full-blown ***declarative*** programming language.
- A super-weapon of a computer scientist.

To be continued.

Simple examples

hello.pro

```
main :-
  write('Hello, world!'),
  nl.
```

```
$ swipl
Welcome to SWI-Prolog (Multi-threaded, 64 bits, Version 5.10.4)
Copyright (c) 1990-2011 University of Amsterdam, VU Amsterdam

?- ['hello.pro'].
% hello.pro compiled 0.00 sec, 992 bytes
true.

?- main.
Hello, world!
true.

?- halt.
$
```

... or use CTRL-D

```
main :-
  write('Hello, world!'),
  nl.

:- main, halt.
```

auto.pro

```
$ swipl -f auto.pro
Hello, world!
$
```

The genealogy use case

```
% Steve's adopted parents

sex(steve,male).
father(paul,steve).
mother(clara,steve).

% Steve's biological parents

father(abdul,steve).
mother(joanne,steve).

% Sister of Steve

sex(mona,female).
father(abdul,mona).
mother(joanne,mona).

% Steve's daughter back from his sterile period

sex(lisa,female).
father(steve,lisa).
mother(anne,lisa).

...
```

http://www.applegazette.com/feature/the-family-tree-of-steve-jobs/

Genealogy relations

```
grandfather(X,Y) :-
  father(X,Z),
  father(Z,Y).

sibling(X,Y) :-
  father(F,X),
  father(F,Y),
  mother(M,X),
  mother(M,Y),
  X \== Y.

sister(X,Y) :-
  sibling(X,Y),
  sex(X,female).
```

Prolog queries

```
% Do we know who Steve's grandfather is?

?- grandfather(X,steve).
false.

% Do we know who Reed's grandfather is?

?- grandfather(X,reed).
X = paul ;
X = abdul ;
false.
```

Genealogy relations cont’d

```
halfsister(X,Y) :-
  sex(X,female),
  father(FX,X),
  mother(MX,X),
  father(FY,Y),
  mother(MY,Y),
  overlap(FX,FY,MX,MY).

overlap(F,F,MX,MY) :- MX \== MY.
overlap(FX,FY,M,M) :- FX \== FY.
```

Use of “disjunction”

```
halfsister(X,Y) :-
  sex(X,female),
  father(FX,X),
  mother(MX,X),
  father(FY,Y),
  mother(MY,Y),
  ( FX == FY, MX \== MY; FX \== FY, MX == MY ).
```

List processing

```
member(X,[X|T]).
member(X,[_|T]) :- member(X,T).

append([H|T],L2,[H|R]) :- append(T,L2,R2).
append([],R,R).
```

```
?- member(X,[a,b,c]).
X = a ;
X = b ;
X = c.

?- append([1,2,3],[4,5,6],X).
X = [1, 2, 3, 4, 5, 6].
```

Directed graphs

```
node(1).
node(2).
node(3).

edge(1,2).
edge(2,3).

connected(X,Y) :-
  edge(X,Y).

connected(X,Y) :-
  edge(X,Z),
  connected(Z,Y).
```

```
?- connected(1,2).
true

?- connected(1,3).
true

?- connected(2,1).
false
```

Implementing Peano axioms

```
add(zero,X,X).
add(succ(X),Y,succ(Z)) :- add(X,Y,Z).
```

```
?- add(succ(succ(zero)),succ(zero),X).
X = succ(succ(succ(zero))).
```

```
?- eval(add(add(num(1),num(2)),num(3)),X).
X = 6.
```

A simple expression interpreter

```
eval(num(N),N) :-
  number(N).

eval(add(E1,E2),N) :-
  eval(E1,N1),
  eval(E2,N2),
  N is N1 + N2.
```

```
?- eval(add(add(num(1),num(2)),num(3)),X).
X = 6.
```

Totaling salaries

http://101companies.org/index.php/101implementation:prolog

```
total(company(_,Ds),R) :-
    total(Ds,R).

total([],0).

total([H|T],R) :-
    total(H,R1),
    total(T,R2),
    R is R1 + R2.

total(dept(_,M,Units),R) :-
    total(M,R1),
    total(Units,R2),
    R is R1 + R2.

total(employee(_,_,S),S).
```

```
?- total(company(me,[dept(leadership,employee(ralf,b127,42),[])]),X).
X = 42.
```

Cutting salaries

http://101companies.org/index.php/101implementation:prolog

```
cut( company(N,Ds1),
     company(N,Ds2)) :-
  cut(Ds1,Ds2).

cut(N1,N2) :-
  number(N1), N2 is N1 / 2.

cut([],[]).
cut([H1|T1],[H2|T2]) :-
  cut(H1,H2), cut(T1,T2).

cut( dept(X,M1,Units1),
     dept(X,M2,Units2)) :-
  cut(M1,M2),
  cut(Units1,Units2).

cut( employee(X,Y,S1),
     employee(X,Y,S2)) :-
  cut(S1,S2).
```

```
?- cut(company(me,[dept(leadership,employee(ralf,b127,42),[])]),X).
X = company(me, [dept(leadership, employee(ralf, b127, 21), [])])
```

Prolog — why?

- Highly declarative.
- Highly operational.
- Highly scripted.
- Highly untyped.
- Highly typeable.
- Highly debuggable.
- **Highly under-appreciated.**
- ...

A super-weapon
of a
computer scientist

Prerequisites

- Propositional logic
- Predicate logic
- Herbrand universe
- Unification
- SLD resolution

You may be able to program w/o knowing these things, but your understanding will be limited.

I/O

File I/O Edinburgh style

```
test :-
  see('eval.sample'),
  read(E),
  seen,
  eval(E,V),
  write(V),
  nl.
```

```
?- test.
6
true.
```

File I/O ISO style

```
test :-
  open('eval.sample',read,In),
  read(In,E),
  close(In),
  eval(E,V),
  write(V),
  nl.
```

```
?- test.
6
true.
```

I/O predicates

- see/1: open file for input, set it as current input
- seen/0: close current input, return to previous one
- read/1: read a term from the input
- tell/1: open file for output, set is as current output
- told/0: close current output, return to previous one
- write/1: write a term to the output
- nl/0: start a new line in the output
- format/2: formatted output
- open/3: open a stream for input or output
- close/1: close a stream
- write/2: write a term to a stream

Debugging

Debugging with traces

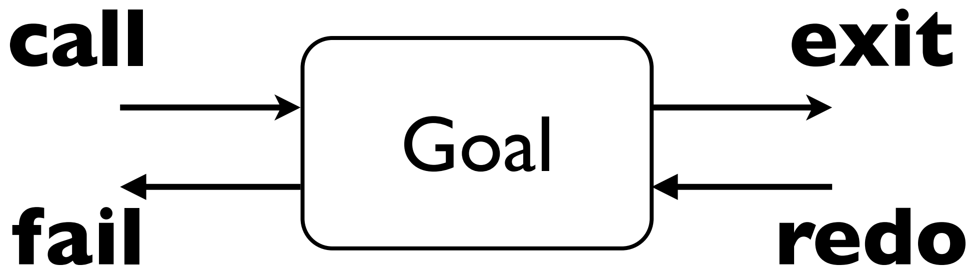
```
?- trace, expr(add(num(1),num(2))).
   Call: (7) expr(add(num(1), num(2))) ? creep
   Call: (8) expr(num(1)) ? creep
   Call: (9) number(1) ? creep
   Exit: (9) number(1) ? creep
   Exit: (8) expr(num(1)) ? creep
   Call: (8) expr(num(2)) ? creep
   Call: (9) number(2) ? creep
   Exit: (9) number(2) ? creep
   Exit: (8) expr(num(2)) ? creep
   Exit: (7) expr(add(num(1), num(2))) ? creep
true.
```

Breakpoints

```
?- spy(number/1).
% Spy point on number/1
true.

[debug]  ?- expr(add(num(1),num(2))).
 * Call: (8) number(1) ? creep
 * Exit: (8) number(1) ? creep
   Exit: (7) expr(num(1)) ? leap
 * Call: (8) number(2) ? leap
 * Exit: (8) number(2) ? leap
true.
```

The *Box Model* of goal execution



- **call**: enter the goal when first attempting proof
- **exit**: leave the goal when completing proof
- **redo**: re-entering goal upon backtracking
- **fail**: ultimately finishing goal when without (further) proof

```
?- spy(number/1).
% Spy point on number/1
true.

[debug]  ?- expr(add(num(1),num(2))).
 * Call: (8) number(1) ? creep
 * Exit: (8) number(1) ? creep
   Exit: (7) expr(num(1)) ? creep
   Call: (7) expr(num(2)) ? Options:
+:                  spy        -:                no spy
/c|e|r|f|u|a goal:  find       .:                repeat find
a:                  abort      A:                alternatives
b:                  break      c (ret, space):   creep
[depth] d:          depth      e:                exit
f:                  fail       [ndepth] g:       goals (backtrace)
h (?):              help       i:                ignore
l:                  leap       L:                listing
n:                  no debug   p:                print
r:                  retry      s:                skip
u:                  up         w:                write
m:             exception details
C:                  toggle show context
   Call: (7) expr(num(2)) ? skip
   Exit: (7) expr(num(2)) ?
```

"skip" can be used to go from "call" to "exit" port right away.

Types and modes

“Types are programs.”

```
expr(num(N)) :- number(N).
expr(add(E1,E2)) :- expr(E1), expr(E2).
```

```
?- expr(add(num(1),num(2))).
true.

?- expr(foo).
false.
```

Another example: finding the max leaf in a tree

```
tree(leaf(X)) :- integer(X).
tree(fork(T1,T2)) :- tree(T1), tree(T2).

max(leaf(X),X).
max(fork(T1,T2),X) :- max(T1,Y), max(T2,Z), X is max(Y,Z).
```

Another operator

```
?- max(fork(leaf(1),fork(leaf(42),leaf(88))),X).
X = 88.
```

Built-in type tests

- number/1
- integer/1
- atom/1
- is_list/1
- ...

```
?- number(1.1).
true.
?- number(foo).
false.
?- integer(1.1).
false.
?- integer(42).
true.
?- atom(42).
false.
?- atom(foo).
true.
?- is_list(foo).
false.
?- is_list([foo]).
true.
```

Flexible modes

```
?- add(X,Y,Z).
X = zero,
Y = Z ;
X = succ(zero),
Z = succ(Y) ;
X = succ(succ(zero)),
Z = succ(succ(Y)) .

?- add(X,Y,succ(succ(zero))).
X = zero,
Y = succ(succ(zero)) ;
X = Y, Y = succ(zero) ;
X = succ(succ(zero)),
Y = zero ;
false.
```

Inflexible modes

```
?- X is 1 + 1.
X = 2.

?- 2 is 1 + 1.
true.

?- 2 is X + 1.
ERROR: is/2: Arguments are not sufficiently instantiated
```

Documentation of modes

- Modes
  - +: needs to be instantiated upon call
  - -: will be instantiated upon exit
  - ?: neither of the two above
- Application to example
  - add(?X,?Y,?Z)
  - is(-X,+Y)

Mode not sufficient here.
We need groundness.

Examples of modes in the list library

- member(?Elem, ?List)
- append(?List1, ?List2, ?List1AndList2)
- append(+ListOfLists, ?List)
- selectchk(+Elem, +List, -Rest)
- permutation(?Xs, ?Ys)
- subset(+SubSet, +Set)

Basic modularization

```
:- ['Company.pro'].
:- ['Total.pro'].
:- ['Cut.pro'].
:- ['Depth.pro'].

:-
   see('sampleCompany.trm'),
   read(C1),
   seen,
   isCompany(C1),
   total(C1,R1),
   format('total = ~w~n',[R1]),
   cut(C1,C2),
   total(C2,R2),
   format('cut = ~w~n',[R2]),
   depth(C1,R3),
   format('depth = ~w~n',[R3]).

 :- halt.
```

Loading all 101companies modules and running tests.

```
% That's a term to be "read".

company(
 'meganalysis',
 [ dept(
    'research',
    employee('Craig','Redmond',123456),
    [ employee('Erik','Utrecht',12345),
      employee('Ralf','Koblenz',1234)
    ]
   ),
   dept(
    'dev',
    employee('Ray','Redmond',234567),
    [ dept(
       'dev1',
       employee('Klaus','Boston',23456),
       [ dept(
          'dev1.1',
          employee('Karl','Riga',2345),
          [ employee('Joe','Wifi City',2344)
          ]
         )
       ]
      )
    ]
   )
 ]
).
```

Basic modularization

% Basic form of input

```
:- consult('MyPrologFile.pro').
```

% Concise notation

```
:- ['MyPrologFile.pro'].
```

% Ensure import (avoid repeated import)

```
:- ensure_loaded('MyPrologFile.pro').
```

Related predicates

% Predicate may be defined in more than file.
:- multifile father/2.

% Clauses may appear discontiguously in file.
:- discontiguous father/2.

% Re-load all files (typically after edits).
:- make.

Declarative vs. operational

Lists versus sets of answers

```
max(X,Y,X) :- X >= Y.
max(X,Y,Y) :- X =< Y.
```

```
?- max(42,88,X).
X = 88.

?- max(42,42,X).
X = 42 ;
X = 42.
```

A single answer is preferred.

Efficiency

```
max(X,Y,X) :- X >= Y.
max(X,Y,Y) :- X < Y.
```

Backtracking ultimately fails.

```
?- max(42,88,X).
X = 88.

?- max(42,42,X).
X = 42 ;
false.
```

Operational reasoning

```
max(X,Y,X) :- X >= Y, !.
max(X,Y,Y) :- X < Y.
```

A green cut

```
?- max(42,88,X).
X = 88.

?- max(42,42,X).
X = 42.
```

No more superfluous backtracking

Destroyed declarative semantics

```
max(X,Y,X) :- X >= Y, !.
max(X,Y,Y).
```

A red cut

```
?- max(42,88,X).
X = 88.

?- max(42,42,X).
X = 42.
```

No problem?

A red cut

```
max(X,Y,X) :- X >= Y, !.
max(X,Y,Y).
```

A green cut

```
max(X,Y,X) :- X >= Y, !.
max(X,Y,Y) :- X < Y.
```

```
?- max(88,42,42).
true.
```

```
?- max(88,42,42).
false.
```

Structured cut

```
(If -> Then); _Else :- If, !, Then.
(If -> _Then); Else :- !, Else.
If -> Then :- If, !, Then.
```

```
max(X,Y,Z) :-
  X >= Y -> Z = X; X = Y.
```

```
?- max(42,88,X).
X = 88.

?- max(42,42,X).
X = 42.

?- max(42,88,42).
false.
```

Looks all good!

Graph example

```
connected(X,Y) :-
  edge(X,Y).

connected(X,Y) :-
  edge(X,Z),
  connected(Z,Y).
```

```
connected(X,Y) :-
  edge(X,Y) ->
    true;
    edge(X,Z),
    connected(Z,Y).
```

Free and bound variables

Terms with variables

- **var/1**: test a term to be a variable
- **ground/1**: test a term to be ground

```
?- var(42).
false.

?- var(X).
true.

?- X=42, var(X).
false.

?- var(foo(X)).
false.
```

```
?- ground(42).
true.

?- ground(X).
false.

?- X=42, ground(X).
X = 42.

?- ground(foo(X)).
false.
```

Use of non-ground terms

```
?- member(Y,[X,Z]).
Y = X ;
Y = Z.
```

```
member(X,[X|T]).
member(X,[_|T]) :- member(X,T).
```

```
?- varmember(Y,[X,Z]).
false
?- varmember(X,[X,Z]).
true
```

```
varmember(V,[H|_]) :- V==H.
varmember(V,[H|T]) :- V\==H, varmember(V,T).
```

Term de-/composition

Inspection of terms

- **functor/3**: observe functor symbol and arity
- **=../2**: take apart compound terms

```
?- functor(foo(bar),X,A).
X = foo,
A = 1.

?- foo(bar) =.. X.
X = [foo, bar].
```

Print terms with indentation

```
print_term(T) :-
  print_term(T,0).

print_term(T,N) :-
  spaces(N),
  ( var(T) ->
      format('~w~n',[T])
    ; T =.. [F|Ts],
      format('~w~n',[F]),
      M is N + 1,
      print_terms(Ts,M) ).

print_terms([],_).

print_terms([H|T],N) :-
  print_term(H,N),
  print_terms(T,N).

spaces(N) :-
  N > 0 -> write(' '), M is N - 1, spaces(M); true.
```

```
?- print_term(add(num
(1),add(num(2),num(3)))).
add
 num
  1
 add
  num
   2
  num
   3
true.
```

Application to
Programming Language Theory

A trivial imperative language: ***syntax***

```
program(Es) :- exprs(Es).

exprs([]).
exprs([E|Es]) :- expr(E), exprs(Es).

expr(N) :- number(N).
expr(E1+E2) :- expr(E1), expr(E2).
expr(V) :- atom(V).
expr(V=E) :- atom(V), expr(E).
```

```
?- program([x=1,y=x+41]).
true
```

A trivial imperative language: ***interpretation***

```
eval(Es,V) :- eval(Es,V,[],_).

eval([E],N,M1,M2) :-
  eval(E,N,M1,M2).
eval([E|Es],N,M1,M2) :-
  Es \== [], eval(E,_,M1,M0), eval(Es,N,M0,M2).
eval(N,N,M,M) :-
  number(N).
eval(E1+E2,N,M1,M2) :-
  eval(E1,N1,M1,M0), eval(E2,N2,M0,M2), N is N1+N2.
eval(V,N,M,M) :-
  atom(V), lookup(V,M,N).
eval(V=E,N,M1,M2) :-
  atom(V), eval(E,N,M1,M0), update(V,N,M0,M2).
```

```
?- eval([x=1,y=x+41],N).
N = 42
```

List-processing convenience

```
lookup(V,[(V,N)|_],N).
lookup(V,[(W,_)|R],N) :- V \== W, lookup(V,R,N).

update(V,N,[],[(V,N)]).
update(V,N,[(V,_)|R],[(V,N)|R]).
update(V,N,[(W,M)|R],[(W,M)|S]) :- V \== W, update(V,N,R,S).
```

Exercises
(in increasing order of difficulty)

Basic list processing

Define a predicate many/3 such that many(+X,+N,-L) creates a list L of length N where all elements are equal to X.

Basic file processing

Write a program that reads two numbers (terms) from a file, computes the sum, and writes the result to another file.

Basic tree processing

Define in-order traversal on an appropriate term representation for binary trees with numbers at the nodes such that the list of all numbers at the nodes is returned.

Syntax evolution

Consider again the syntax for the simple imperative programming language, as it was defined and interpreted earlier:

```
[x=1,y=x+41]
```

Revise the predicates program/1 and eval/2 (and friends) so that a more uniform syntax is used instead:

```
[assign(x,num(1)),
 assign(y,add(var(x),num(41)))]
```

Syntax evolution (variation)

Hard!

Consider again the syntax for the simple imperative programming language, as it was defined and interpreted earlier. Rather than using atoms for the program variables, use instead Prolog variables.

End of Lecture (EOL)