DATA MODELLING IN ENGINEERING

MODELING BASED ON LOGIC PROGRAMMING – PART III -

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2024 - 2025

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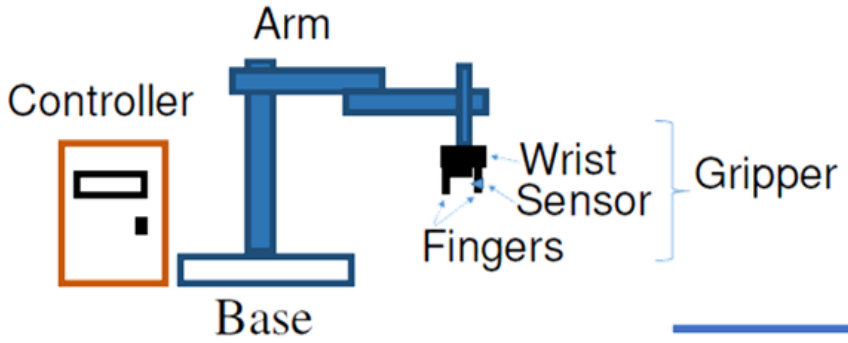
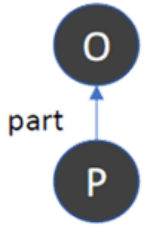
Facts / Rules / Queries

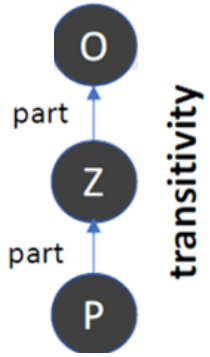
… from previous class …

Going back to the robot model example:
We can generalize the rule





includes(O,P) :- part(O,P). /* O includes P **if** O has a part P */
includes(O, P) :- part(O,Z), part(Z,P). /* O includes P **if** O has a part Z **and** Z has a part P*/



<u>One possible solution</u>:

```
part(robot, base).
part(robot, arm).
part(robot, gripper).
part(robot, controller).
part(gripper, wrist).
part(gripper, fingers).
part(gripper, sensor).
```

A more generic solution

contains(O,P) :- part(O,P). /* O contains P **if** O has part P */
contains(O,P) :- part(Z,P), **contains(O,Z)**. /* O contains P **if** Z has part P **and** O contains Z */

The 2nd rule is defined in t
… i.e. recursive definition

recursion mechanism

Structures / Combined Queries

… from previous class …

```
/*      #id,     name, age, birthdate, address  */
person(31267389, john,   birthdate(24,11,2000), address('R Bernardo Marques', 7, 'Caprica')).
person(43261876, mary,   birthdate(16,06,2001), address('R Francisco Costa', 5, 'Caprica')).
person(36482754, jane,   birthdate(30,01,2004), address('R Garcia de Orta', 3, 'Almada')).
person(37392715, thomas, birthdate(05,03,2000), address('R Alfredo Cunha', 9, 'Caprica')).
```

…

Identify by name, people that live in Almada:

?- person(_, N, _, address(_, _, 'Almada')).

N = jane.

```
/*        Nr, Name, gender, year    */
student(65200, 'Ademir Paulo Santos Caetano',m,3).
student(65145, 'Afonso Aleixo Vieira Gonçalves Varela',m,3).
student(65405, 'André Filipe Freitas Mendes',m,3).
student(65368, 'André Gomes Antunes',m,3).
student(54543, 'António Manuel Sebastião Ferreira Deveza',m,3).
student(65499, 'Beatriz Flórido Pereira',f,3).
student(65243, 'Bernardo de Oliveira Lopes Garcia Barata',m,3).
% ...
student(66092, 'Vasco Cananão Mendes',m,3).

gender(f, female).
gender(m, male).
```

What is the gender of student nº 65405 ?

?- student(65405,_,G,_) , gender(G,Gender).

and

G = m , Gender = male.

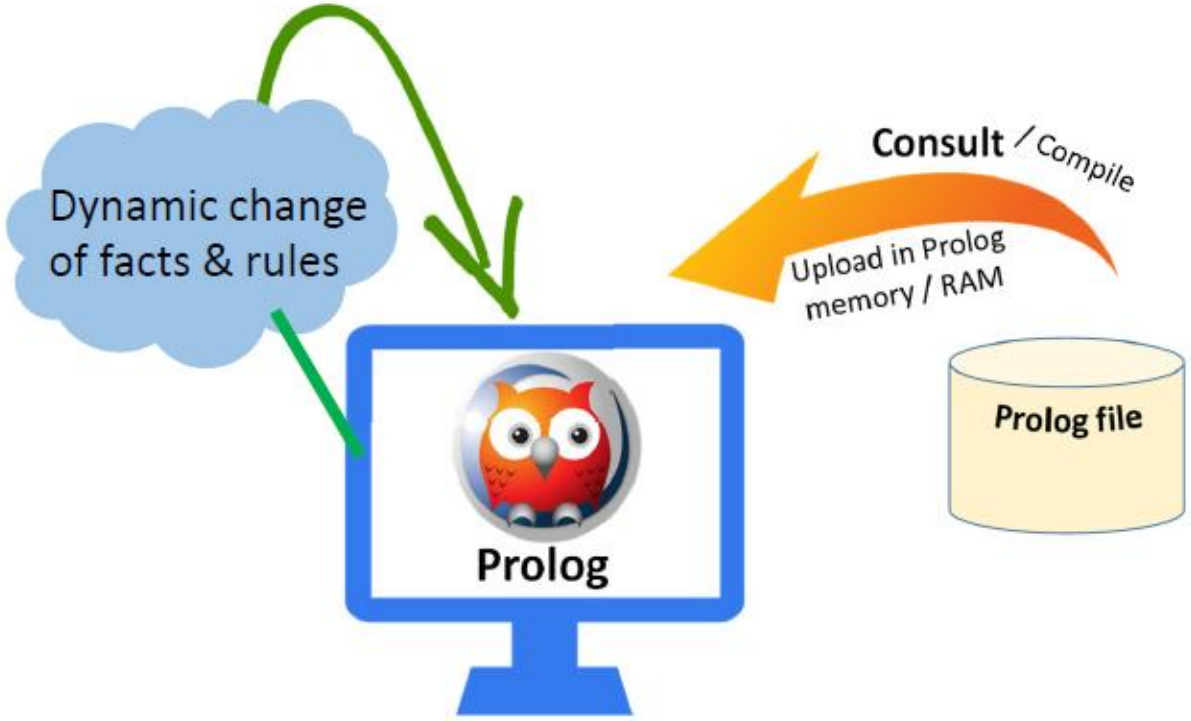
What are the numbers female students ?

?- gender(G,female) , student(N,_,G,_).

G = f , N = 65499.

Changing the Memory in Prolog

… from previous class …



assert(S)
asserta(S)
assertz(S)

To add facts / rules

retract(S)
Retractall(S)

To remove/delete facts / rules

Informs the interpreter that the definition of the predicate(s) may change during execution (using assert/1 and/or retract/1)

:-dynamic fact/args

List matching clauses

listing(X)

Input / Output

… from previous class …

Exercise

Let's get back to the example of fathers and create a menu for a "FATHERS MANAGEMENT SYSTEM ☺"

```
gmenu:- nl,nl,write('FATHERS MANAGEMENT SYSTEM :)'),nl,
    menu(Op), execute(Op).

menu(Op):- write('1. List fathers'),nl,
    write('2. Insert father'),nl,
    write('3. Delete fathers'),nl,
    write('4. Exit'), nl, readoption(Op).

readoption(Op):- read(Op),valid(Op),nl.
readoption(Op):- nl, write('*** Invalid option. Try again: '), readoption(Op).

valid(Op):- Op >=1, Op=<4.

execute(4). % exit condition
execute(Op):- exec(Op),nl,
    menu(NOp),execute(NOp).

exec(1) :- listing(father).
exec(2) :- read_fathers.
exec(3) :- delete_fathers.
```

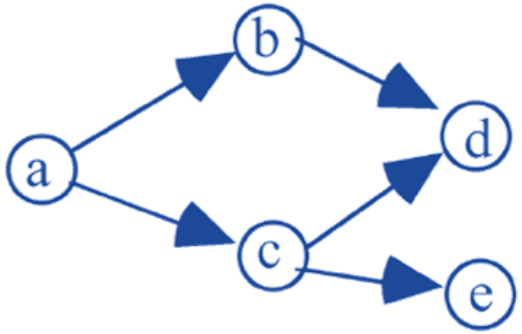
```
FATHERS MANAGEMENT SYSTEM :)
1. List fathers
2. Insert father
3. Delete fathers
4. Exit
```

Here we use some pre-defined rules of SWI-Prolog:
read – reads a string ended by "."
write – writes a string
nl – new line

Directed Graph

Back to modeling….

Examples of application: road maps (one direction), electric circuits, energy distribution, ...



One possible representation:

Facts:

arc(a,b).
arc(a,c).
arc(b,d).
arc(c,d).
arc(c,e).

Recursive definition

Rules:

R1 connected(X,Y) :- arc(X,Y).

R2 connected(X,Y) :- arc(X,Z), connected(Z,Y).

?- connected(a,b).

Rule 1: connected(a,b) :- arc(a,b) ➔ succeeds

true

?- connected(a,d).

Rule 1: connected(a,d) :- arc(a,d) ➔ fails
Rule 2: connected(a,d) :- arc(a, Z), connected (Z,d)

Z=b Rule 1: connected(b,d) :- arc(b,d) ➔ succeeds

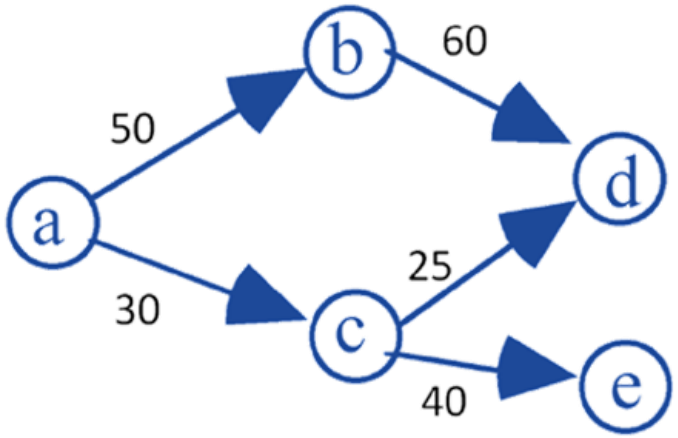
true

from @L.M. Camarinha-Matos 2023

Directed Graph

Back to modeling….

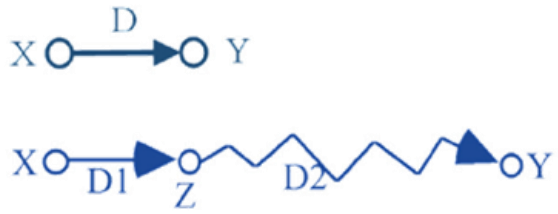
Arcs with distance



dist(a,b,50).
dist(a,c,30).
dist(b,d,60).
dist(c,d,25).
dist(c,e,40).

R1 distance(X,Y,D) :- dist(X,Y,D).

R2 distance(X,Y,D) :- dist(X,Z,D1),
distance(Z,Y, D2),
D is D1 + D2.



?- distance(a,d,D).

Rule 1: distance(a,d,D) :- dist(a,d, D) ➔ fails
Rule 2: distance(a,d,D) :- dist(a, Z, D1), distance(Z,d, D2), D is D1+D2

Z=b D1=50 Rule 1: distance(b,d,D2) :- dist(b,d,D2)

D2=60

D = 110 ;

D = 55

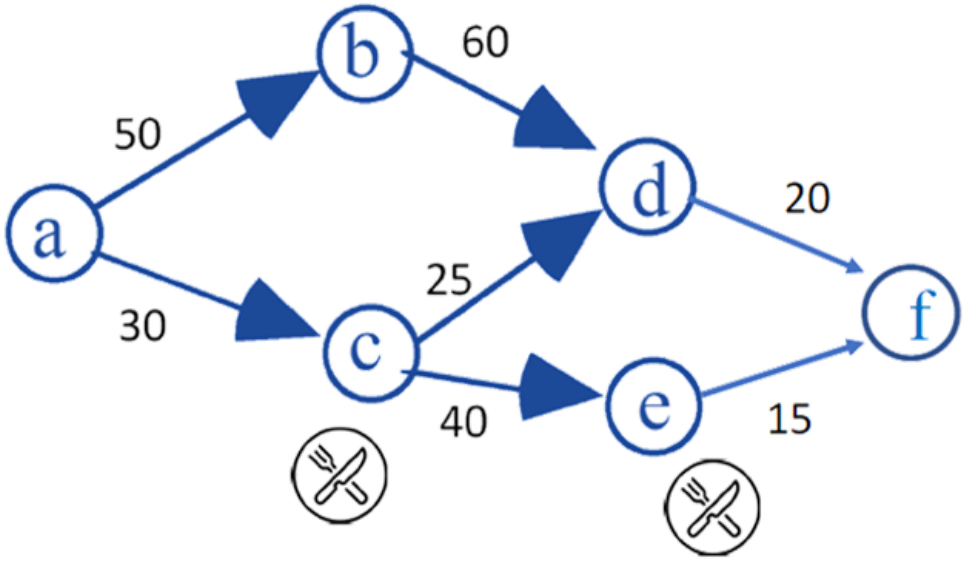
Try another solution

from @L.M. Camarinha-Matos 2023

Directed Graph

Back to modeling….

Variant:
Imagine that the graph represents a road map (nodes represent cities, arcs represent roads). In order to go from city X to city Y, either there is a direct road, or in case we must pass by intermediate cities we only want to pass by cities with a restaurant. Some cities have restaurants, others not.



Represent the case illustrated in the figure.

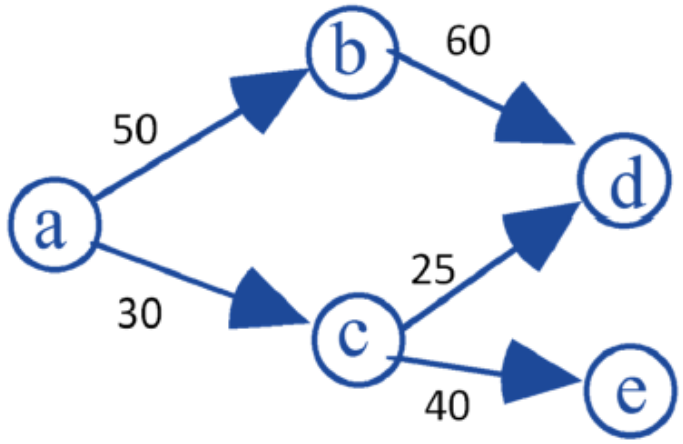
Modify the rule distance in order to consider the constraint indicated above (i.e., only passing by intermediate nodes with a restaurant).

How many valid paths between a and f?

from @L.M. Camarinha-Matos 2023

Directed Graph

Back to modeling….



Facts:

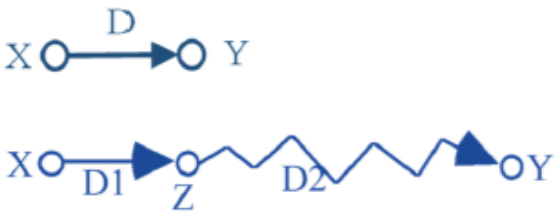
arc(a,b).	dist(a,b,50).
arc(a,c).	dist(a,c,30).
arc(b,d).	dist(b,d,60).
arc(c,d).	dist(c,d,25).
arc(c,e).	dist(c,e,40).

Rules:

Recursive definition

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

```
distance(X,Y,D) :- dist(X,Y,D).
distance(X,Y,D) :- dist(X,Z,D1),
                   distance(Z,Y, D2),
                   D is D1 + D2.
```



But what if we want to know the names of all nodes in the path between two nodes X and Y?

The answer can be of a variable length, depending on X, Y and the followed path => thus, **we need another data structure** to represent such answers with variable length

from @L.M. Camarinha-Matos 2023

Lists in PROLOG

List: a data structure that can contain a variable number of elements

Some notation:

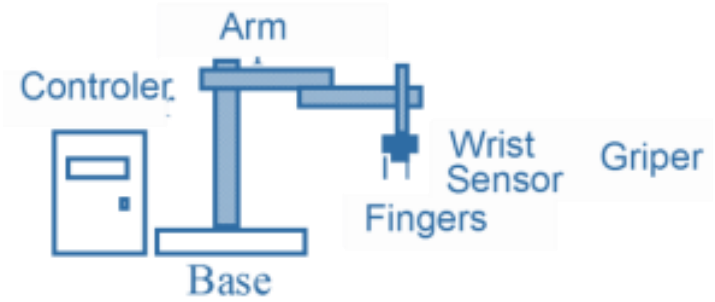
[]	empty list
[a]	list with 1 element
[a, b]	list with 2 elements
[a, [b, c], d]	list with 3 elements
[a, date(11,3,94), b]	list with 3 elements
[H | R]	list with at least 1 element H – first element (head) R - list with remaining elements (excluding head)
[X1, X2 | R]	list with at least 2 elements

from @L.M. Camarinha-Matos 2023

Lists: examples

Example:

components(robot, [base, arm, gripper, controller]).
components(gripper, [wrist, fingers, sensor]).



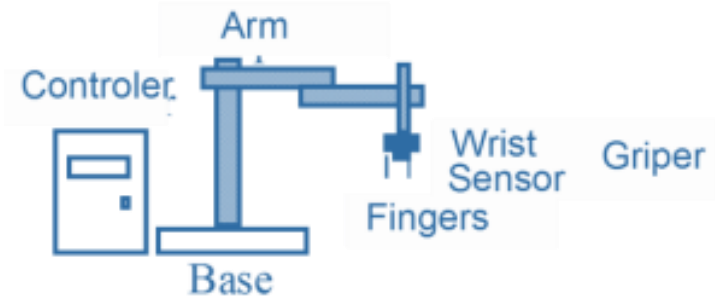
?-components(robot, L).
L = [base, arm, gripper, controller]

?-components(gripper, [C|R]).
C = wrist
R = [finger, sensor]

?-components(X, [base | _]).
X = robot

from @L.M. Camarinha-Matos 2023

Lists: examples



Example: Is the element E a **member** of a given list?

```
is_member(E, [E|_]).
is_member(E, [_|R]) :- is_member(E,R).
```

```
components(robot, [base, arm, gripper, controller]).
components(gripper, [wrist, fingers, sensor]).
```

```
has(O,C) :- components(O,L), is_member(C,L).

?-has(gripper, fingers).
true
```

```
?-components(robot,L), is_member(E,L).
L = [base, arm, gripper, controller],
E = base ;
L = [base, arm, gripper, controller],
E = arm ;
L = [base, arm, gripper, controller],
E = gripper ;
L = [base, arm, gripper, controller],
E = controller ;
false.
```

from @L.M. Camarinha-Matos 2023

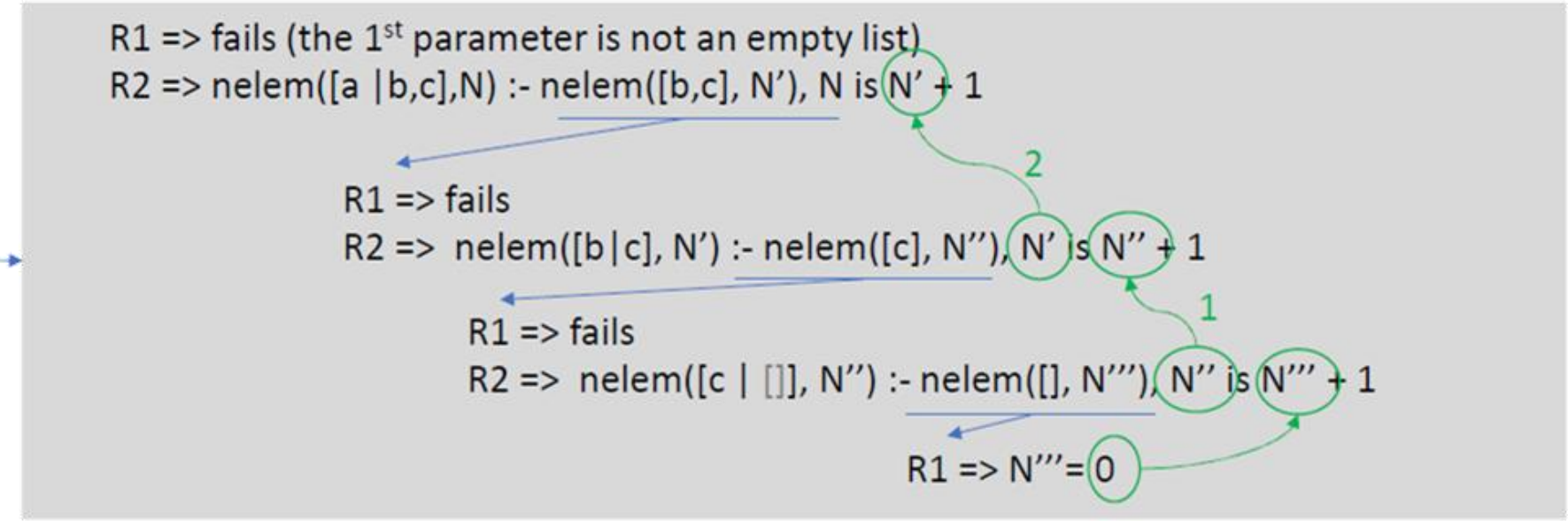
Lists: examples

Example: **Length** or number of elements of a list

R1 nelem([], 0).
R2 nelem([_|R],N) :- nelem(R, N1), N is N1 + 1.

?- nelem([a, b, c], N).

Invisible to the user



N = 3

from @L.M. Camarinha-Matos 2023

Lists: examples

Example: Rule to find the **maximum** of a list

R1 max([X], X).
R2 max([X | R], X) :- max(R, M), X >= M.
R3 max([X | R], M) :- max(R,M), X < M.

?- max([4, 3, 8], M).

R1 => fails
R2 => max([4|[3,8]], 4):- max([3,8],M'), 4 >= M'

R1 => fails
R2 => max([3|[8]], 3):- max([8],M'), 3 >= M'

R1 => max([8]], 8) => M'= 8

R2 => fails
R3 => max([3|[8]], M):- max([8],M), 3 < M

R1 => max([8]], 8) => M= 8

R2 => fails
R3 => max ([4|[3,8]], M):- max ([3,8], M), 4 < M

R1 => fails
R2 => max([3|[8]], 3):- max([8],M'), 3 >= M'

R1 => max([8]], 8) => M'= 8

R2 => fails
R3 => max([3|[8]], M):- max([8],M), 3 < M

R1 => max([8]], 8) => M= 8

M = 8

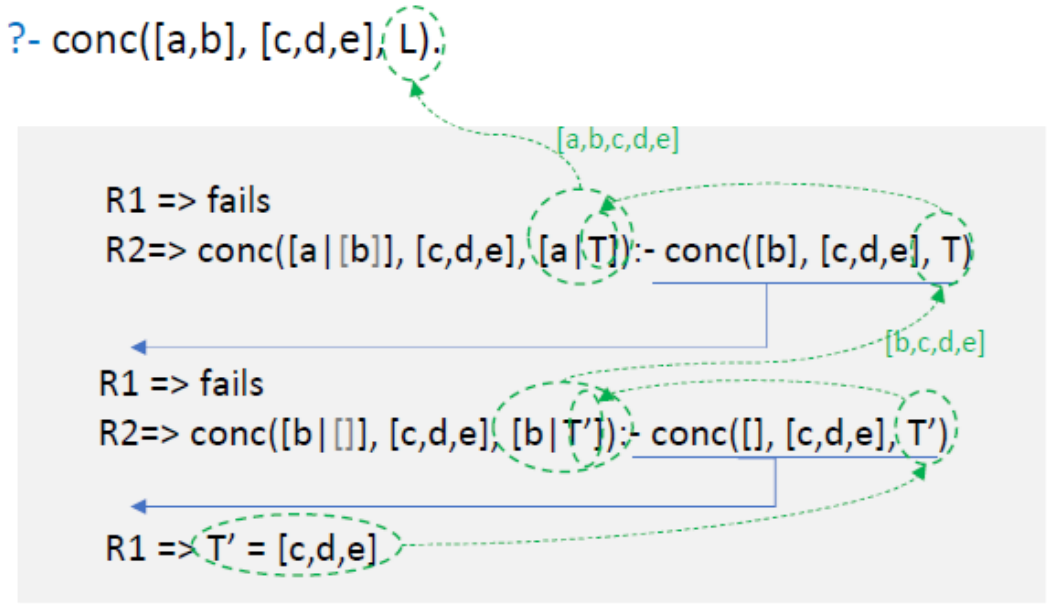
from @L.M. Camarinha-Matos 2023

Lists: examples

Example: **concatenate** two lists

[a, b] + [c, d, e] => [a, b, c, d, e]

```
conc([], L, L).
conc([C|R], L, [C|T]) :- conc(R, L, T).
```



L = [a,b,c,d,e]

Example: **invert** a list

```
invert([], []).
invert([C|R], I) :- invert(R, Ri), conc(Ri, [C], I).
```

?-invert([a,b,c], I).
I = [c,b,a]

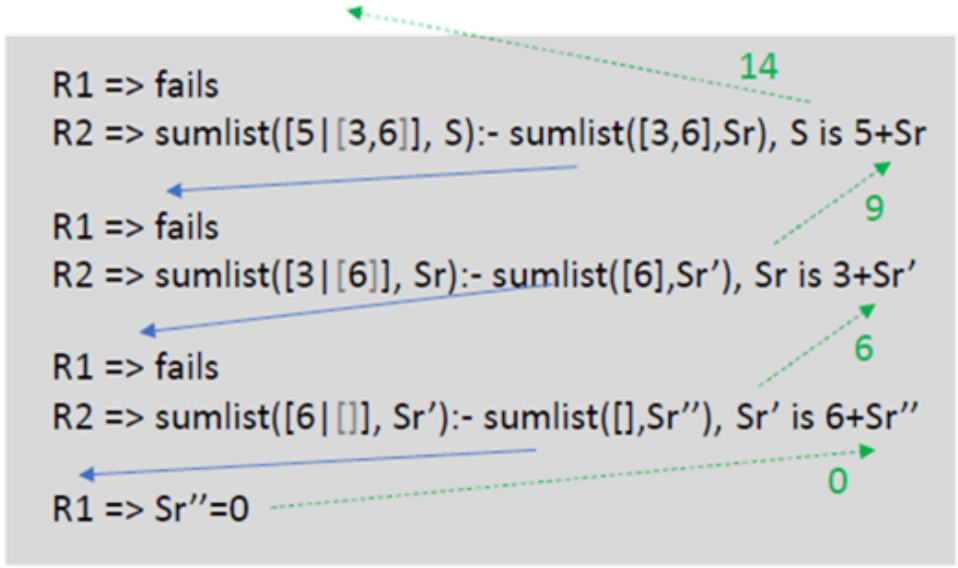
from @L.M. Camarinha-Matos 2023

Lists: examples

Given a list of numbers, **add** those numbers.

```
sumlist([],0).
sumlist([X|R], S):- sumlist(R,Sr), S is X + Sr.
```

```
?-sumlist([5,3,6], S).
```



S = 14

Given a list of numbers, calculate the **average** of those numbers.

```
avglist([],0).
avglist(L,A):- sumcount(L,N,S), A is S/N.
sumcount([],0,0).
sumcount([X|R],N,S):- sumcount(R,Nr,Sr),
                      N is Nr+1,S is Sr+X.
```

```
?-avglist([6,8,10],A).
A= 8
```

from @L.M. Camarinha-Matos 2023

Lists: examples

Proposed exercises:

E1: Consider a list in which elements might appear repeated. Write a set of rules to calculate the number of times one element E appears repeated in a given list.

E2: Write a set of rules to find the minimum of a list.

E3: Find the last element of a list.

Example:
?- my_last(X,[a,b,c,d]).
X = d

E4: Duplicate the elements of a list.

Example:
?- dupli([a,b,c,c,d],X).
X = [a,a,b,b,c,c,c,c,d,d]

E5: Extract a slice from a list.

Given two indices, I and K, the slice is the list containing the elements between the I'th and K'th element of the original list (both limits included). Start counting the elements with 1.
Example:
?- slice([a,b,c,d,e,f,g,h,i,k],3,7,L).
X = [c,d,e,f,g]

from @L.M. Camarinha-Matos 2023

Lists: examples

E6: Suppose we are given a knowledge base with the following facts:

```
tran(um,one).
tran(dois,two).
tran(tres,three).
tran(quatro,four).
tran(cinco,five).
tran(seis,six).
tran(sete,seven).
tran(oito,eight).
tran(nove,nine).
```

Write a predicate listtran(G,E) which translates a list of Portuguese number words to the corresponding list of English number words. For example:

```
listtran([um,nove,dois],X).
```

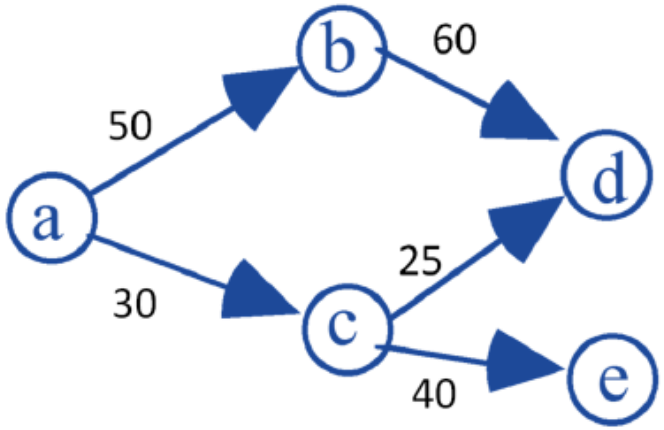
should give:

```
X = [one,nine,two].
```

from @L.M. Camarinha-Matos 2023

Lists and Graphs

Graph revisited:




```
dist(a,b,50).
dist(a,c,30).
dist(b,d,60).
dist(c,d,25).
dist(c,e,40).
```

Obtain, in a list, the arcs of the **path** between two nodes X, Y

Solution 1:

R1 path(X,Y, [dist(X,Y,D)]) :- dist(X,Y,D).

R2 path(X,Y, [dist(X,Z,D) | R]) :- dist(X,Z,D), path(Z,Y,R).

?- path(a, d, P).

R1=> path(a, d, [dist(a, d, D)]) :- dist(a, d, D) => fails

R2=> path(a, d, [dist(a,Z,D) | R]):- dist(a,Z,D), path(Z,d,R)

Z=b, D=50

R1=> path(b, d, [dist(b, d, D')]) :- dist(b, d, D')

D'=60

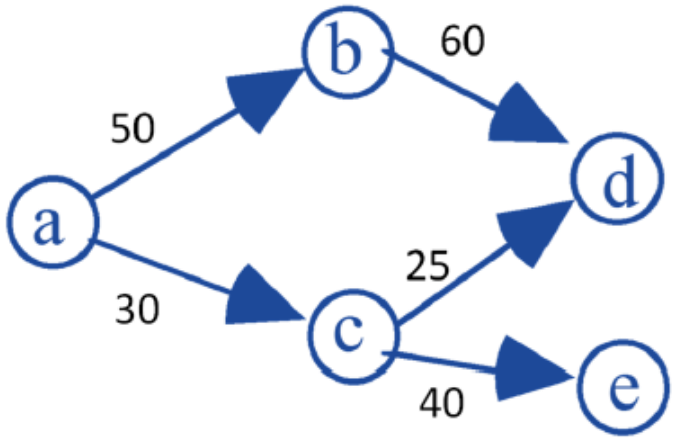
P = [dist(a,b,50), dist(b,d,60)] ; ← *Try another solution*

P = [dist(a,c,30), dist(c,d,25)]

from @L.M. Camarinha-Matos 2023

Lists and Graphs

Graph revisited:




```
dist(a,b,50).
dist(a,c,30).
dist(b,d,60).
dist(c,d,25).
dist(c,e,40).
```

Obtain, in a list, the arcs of the path between two nodes X, Y

Solution 2:

```
path(X,Y, [via(X,Y)]) :- dist(X,Y,_).
path(X,Y, [via(X,Z) | R]) :- dist(X,Z,_), path(Z,Y,R).

?- path(a, d, P).

P = [via(a,b), via(b,d)]  ;
P = [via(a,c), via(c,d)]
```

Solution 3:

```
path(X,Y, [(X,Y)]) :- dist(X,Y,_).
path(X,Y, [(X,Z) | R]) :- dist(X,Z,_), path(Z,Y,R).

?- path(a, d, P).

P = [(a,b), (b,d)] ;
P = [(a, c),  (c, d)] ;
false.
```

There are no more solutions

from @L.M. Camarinha-Matos 2023

Lists and Graphs

Write another version of path with the following behavior:

?-path3(a,e,P).

P = p([via(a, c, 30), via(c, e, 40)], 70) *Total distance*

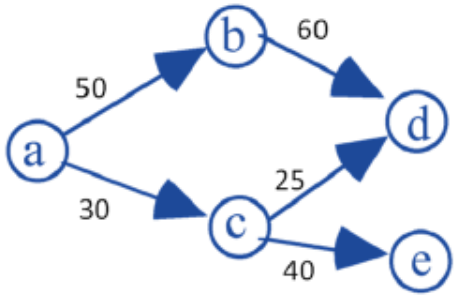
```
path4(X,Y, [via(X,Y,D)], D) :- dist(X,Y,D).

path4(X,Y, [via(X,Z,D1) | R], DT) :- dist(X,Z,D1),
                                     path4(Z,Y, R,D2), DT is D1+D2.
```

```
?-path4(a,d,P, D).
P= [via(a,b,50), via(b,d,60)].
D=110
```

path3(X,Y, p([via(X,Y,D)], D)) :- dist(X,Y,D).

path3(X,Y, p([via(X,Z,D1) | R], DT)) :- dist(X,Z,D1), path3(Z,Y, p(R,D2)), DT is D1+D2.




```
?- path3(a,d,P).
P = p([via(a, b, 50), via(b, d, 60)], 110) ;
P = p([via(a, c, 30), via(c, d, 25)], 55) ;
false.
```

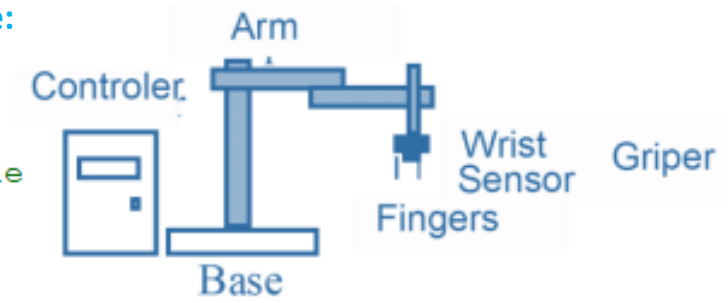
```
?- path3(a,e,P).
P = p([via(a, c, 30), via(c, e, 40)], 70) ;
false.
```

```
?- path3(c,e,p([via(c,e,40)],40)).
true
```

from @L.M. Camarinha-Matos 2023

Lists -> Multiple Solutions: findall

Remember the Robot example:




```
% modeling robot example
part(robot,base).
part(robot,arm).
part(robot,griper).
part(robot,controler).
part(griper,wrist).
part(griper,fingers).
part(griper,sensor).
part(sensor,glass).
```

(…)

Obtaining all solutions -> **;**

```
?- part(_,P).
P = base ;
P = arm ;
P = griper ;
P = controler ;
P = wrist ;
P = fingers ;
P = sensor ;
P = glass.
```

Variable for which we want to find the value

Query, involving variable V

findall(V, query, LA)

A pre-defined rule in Prolog

List containing all possible values for V

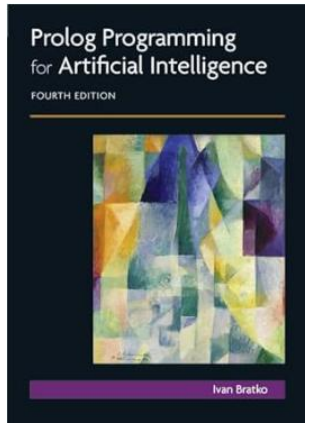
?-findall(P,part(_,P),L).
L = [base,arm,griper,controller,wrist,fingers,sensor,glass].

?-findall(part(C,P),part(C,P),L).
L = [part(robot,base), part(robot,arm), part(robot,griper), part(robot,controller), part(griper,wrist), part(griper,fingers), part(griper,sensor), part(sensor,glass)].

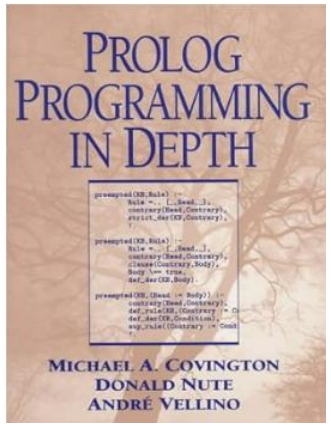
?-findall([C,P],part(C,P),L).
L = [[robot,base], [robot,arm], [robot,griper], [robot,controller], [griper,wrist], [griper,fingers], [griper,sensor], [sensor,glass]].

findall(p(C,P),part(C,P),L).
L = [p(robot,base), p(robot,arm), p(robot,griper), p(robot,controller), p(griper,wrist), p(griper,fingers), p(griper,sensor), p(sensor,glass)].

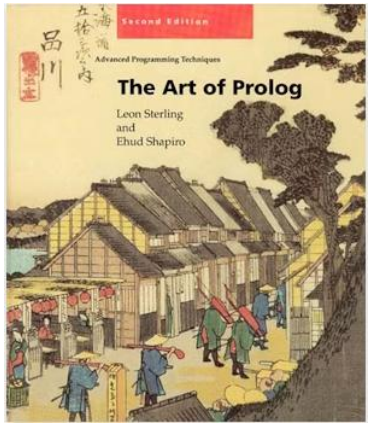
Further reading



https://www.amazon.com/Programming-Artificial-Intelligence-International-Computer/dp/0321417461



https://www.amazon.com/Prolog-Programming-Depth-Michael-Covington/dp/013138645X/ref=pd_sim_14_4?ie=UTF8&dpID=514M0RXA1WL&dpSrc=sims&preST=_AC_UL160_SR122%2C160_&refRID=1TM7A3CEFC2BD4JA77WR



https://mitpress.mit.edu/9780262691635/the-art-of-prolog/

(...)

https://www.swi-prolog.org/pldoc/doc_for?object=manual

https://en.wikibooks.org/wiki/Prolog

https://drsmithbiology.weebly.com/further-reading.html

Good Work!

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