An introduction to Prolog

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1 Prolog

2 Functions

3 Flow control

4 Other features

A first glimpse at Prolog

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- Well suited for symbolic, non-numeric computation. Good for dealing with objects and relations.
- Let us start with facts (ground atoms) for some relations (predicates).

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  Felipe and Letizia have two children:

  ```
  father(felipe,leonor).
  father(felipe,sofia2).
  mother(letizia,leonor).
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  ```

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?- mother(sofia,X).
?- father(X,Y).
?- mother(X,Y), father(Y,leonor).
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- How would you check whether Cristina and Elena have the same father?

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- The comma means conjunction. These queries are logically equivalent:

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  Notice that the two '_' are different irrelevant variables.

Adding rules

- We can “give name” to queries using rules. For instance, for:

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we can define a new predicate `grandmother` using:

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- In first order logic, we would write:

$$\forall x \forall y \forall z\ (\ Mother(x,y) \wedge Father(y,z) \rightarrow Grandmother(x,z)\ )$$

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$$\forall x \forall y \forall z\ \big(\ Mother(x,y) \wedge Father(y,z) \rightarrow Grandmother(x,z)\ \big)$$

- We can use it now in queries:

```
?- grandmother(X,leonor).
```

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- We may have several rules to define a predicate.

Adding rules

If prolog can't unify the first conjunction of objectives (body rule) for any value of X,Y,Z. Prolog do backtrack and jumps to the next body rule that defines the predicate grandmother in which mother(Y,Z) is included

- We may have several rules to define a predicate. For instance, my mother's mother is also my grandmother:

```
grandmother(X,Z) :- mother(X,Y), father(Y,Z).
grandmother(X,Z) :- mother(X,Y), mother(Y,Z).
```

  to obtain solutions to `?- grandmother(X,Y).` we can apply any of these rules.

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- Exercises: who are Felipe's parents? Redefine `grandmother` with a single rule using the `parent` relation.

Aquí quedé 12/03/2025

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female(leonor).   female(sofia2).
```

  but we can also derive it from `mother`

```
female(X) :- mother(X,_).
```

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- Exercise: define the `sister` relation.

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sister(X,Y) :- parent(Z,X), parent(Z,Y), female(X).

?- sister(felipe,X).
?- sister(leonor,X).
```

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- Exercise: define the `sister` relation.

```
sister(X,Y) :- parent(Z,X), parent(Z,Y), female(X).
```

```
?- sister(felipe,X).
?- sister(leonor,X).
```

- Problem: Leonor is sister of herself! We should specify that they are different:

```
sister(X,Y) :- parent(Z,X),parent(Z,Y),
              female(Y), X \= Y.
```

Recursion

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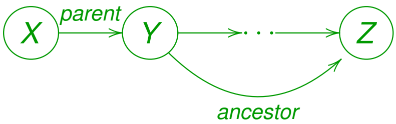

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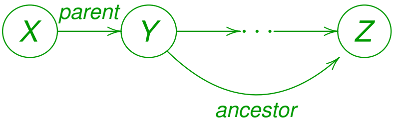


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ancestor(X,Y)  :- parent(X,Y).
ancestor(X,Z)  :- parent(X,Y), ancestor(Y,Z).
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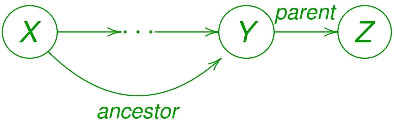

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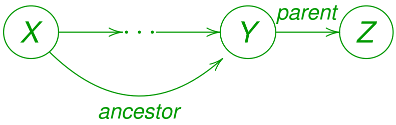


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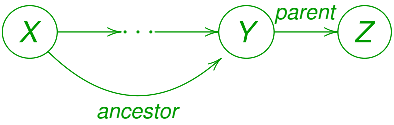


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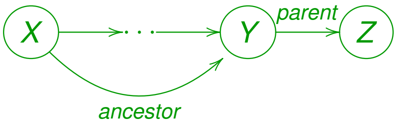


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but Prolog further introduces an evaluation ordering that, for instance, causes query `?- ancestor(X,juancarlos)` to iterate forever.

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- So, how does this work? Take

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- As matching succeeded, we replace our initial goal by the rule body `parent(sofia,leonor)`, which becomes our new goal.

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- We try then to match `parent(sofia,leonor)` with some rule head. This predicate has two rules

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parent(X,Y) :- father(X,Y).
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- However, `father` is extensional (only facts), and this fact is not included in the program. So, our goal fails.

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- A failure implies backtracking to the last matching, and looking for new matches.

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- So we "reconsider" the last deleted goal `parent(sofia,leonor)` and try to match another rule

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parent(X,Y) :- father(X,Y).   (failed)
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- Now, `parent(sofia,leonor)` has failed in its turn. We backtrack to `ancestor(sofia,leonor)` looking for another matching head.

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- Matching `parent(sofia,Y)` with `parent(X',Y') :- mother(X',Y').` leads to new goal `mother(sofia,Y)` that succeeds for `Y=felipe` (more matchings are possible).

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- Now we have a list of goals `parent(sofia,Y), ancestor(Y,leonor).`
- Matching `parent(sofia,Y)` with `parent(X',Y') :- father(X',Y').` is possible under replacement `X'=sofia, Y'=Y`. This leads to new goal `father(sofia,Y)` that fails.
- Matching `parent(sofia,Y)` with `parent(X',Y') :- mother(X',Y').` leads to new goal `mother(sofia,Y)` that succeeds for `Y=felipe` (more matchings are possible).
- Important: assignment `Y=felipe` affects our whole list of goals.

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- Now we have a list of goals `parent(sofia,Y), ancestor(Y,leonor).`
- Matching `parent(sofia,Y)` with `parent(X',Y') :- father(X',Y').` is possible under replacement `X'=sofia`, `Y'=Y`. This leads to new goal `father(sofia,Y)` that fails.
- Matching `parent(sofia,Y)` with `parent(X',Y') :- mother(X',Y').` leads to new goal `mother(sofia,Y)` that succeeds for `Y=felipe` (more matchings are possible).
- Important: assignment `Y=felipe` affects our whole list of goals. That is, `ancestor(Y,leonor)` becomes `ancestor(felipe,leonor).`

Top-down goal satisfaction

- Matching `ancestor(felipe,leonor)` with `ancestor(X,Y) :- parent(X,Y).` leads to goal `parent(felipe,leonor)`.

Top-down goal satisfaction

- Matching `ancestor(felipe,leonor)` with `ancestor(X,Y) :- parent(X,Y).` leads to goal `parent(felipe,leonor)`.
- Finally, matching `parent(felipe,leonor)` with `parent(X,Y) :- father(X,Y).` leads to new goal `father(felipe,leonor)` that succeeds.

Top-down goal satisfaction

- Matching `ancestor(felipe,leonor)` with `ancestor(X,Y) :- parent(X,Y).` leads to goal `parent(felipe,leonor)`.
- Finally, matching `parent(felipe,leonor)` with `parent(X,Y) :- father(X,Y).` leads to new goal `father(felipe,leonor)` that succeeds. Prolog answers `Yes`!

1 Prolog

2 Functions

3 Flow control

4 Other features

Adding functions

- We can use function symbols to pack some data together as a single structure. Example:

```
born(juancarlos,f(5,1,1938)).
born(felipe,f(30,1,1968)).
born(letizia,f(15,9,1972)).
born(sofia,f(2,11,1938)).

later(f(_,_,Y), f(_,_,Y1)) :- Y>Y1.
later(f(_,M,Y), f(_,M1,Y)) :- M>M1.
later(f(D,M,Y), f(D1,M,Y)) :- D>D1.

birthday(X,d(D,M)) :- born(X,f(D,M,_)).
```

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- Predicate $>$ is predefined for arithmetic values.

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Some examples of queries:

- Which is Juan Carlos' date of birth?

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- Which is Sofia's birthday? `?- birthday(sofia,X).`

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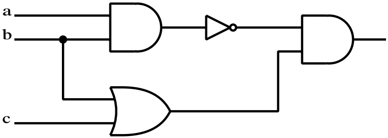
- We can use the same name for functors with different arity. For instance, we could have written:
  `birthday(X,date(D,M)) :- born(X,date(D,M,_)).`
- As in First Order Logic, we call terms to any combination of functions, constants and variables. In fact, a constant `c` is a 0-ary functor `c/0`.

Adding functions

- Example: we can represent a digital circuit.

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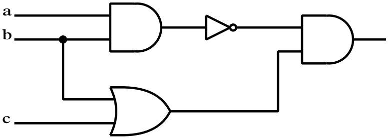


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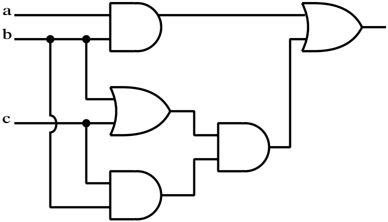
- Exercise: try to represent this circuit



- Arithmetic operators are also (infix) functors. The term `2+3*4` is not equal to `4*3+2` or `14`.

User-defined functors

- We can also define our own functors using the `op` directive.

```
:- op(X,Y,Z).
```

  means we declare operator `Z` with precedence number `X` (higher = less priority) and associativity `Y`.

- Associativity can be:
  - infix operators: `xfx` `xfy` `yfx`
  - prefix operators: `fx` `fy`
  - postfix operators: `xf` `yf`

  where:
  - `f`: is the functor position
  - `x`: argument of strictly lower precedence
  - `y`: argument of lower or equal precedence

User-defined functors

- For instance, the fact:

  ```
  equivalent(not(and(A,B)), or(not(A),not(B))).
  ```

  can be written in a more readable way:

  ```
  :- op(800,xfx,<==>).
  :- op(700,xfy,v).
  :- op(600,xfy,&).
  :- op(500,fy,not).
  not (A & B) <==> not A v not B.
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- Try the following `?- F=(not a v b & c), F=(H v G).`
- Note that `= > < :- ,` are predefined operators. Predicate `current_op/3` shows the currently defined operators.

Exercise 1

Build a predicate `eval/5` *that computes the output of any circuit for 3 variables so that* `eval(A,B,C,Circuit,X)` *returns the output of* `Circuit` *in* `X` *for values* `a=A`, `b=B` *and* `c=C`.
The predicate must also allow returning the models of the circuit (combinations of values that yield a 1).
Try with the two previous circuits.

Examples:

```
?- eval(1,0,0, a & ( not b v c) ,X).
X = 1.

?- eval(A,B,C, a v not b,1).
A = 1, B = 1 ;
A = 0, B = 0 ;
A = 1, B = 0 ;
```

Unification

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- To see how it works, we can use the built in `=/2` Prolog predicate. Try the following:

```
?- f(X,b)=f(a,Y).
?- f(X,b)=f(X,Y).
?- f(f(Y),b)=f(X,Y).
?- f(f(Y),b)=f(a,Y).
```

Unification

- The general algorithm is well-known: Most General Unifier (MGU) [Robinson 1971].
- Given a set of expressions E, we compute a disagreement set searching from left to right the first different symbol and taking the corresponding subexpression.

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- Given a set of expressions E, we compute a disagreement set searching from left to right the first different symbol and taking the corresponding subexpression.
- For instance, given $p(f(X), Y)$ and $p(f(g(a, Z), f(Z))$ we get the disagreement set $\{X, g(a, Z)\}$.

Unification

- If two atoms can be unified, they have an MGU that can be computed as follows:

$$
\begin{array}{l}
\sigma := [\,];\\
\text{while } |E| > 1 \ \{\\
\quad D := \text{disagreement set of } E;\\
\quad \text{if } D \text{ contains an } X \text{ and a term } t \text{ not containing } X \ \{\\
\quad\quad \left.\begin{array}{l} E := E[X/t];\\ \sigma := \sigma \cdot [X/t]; \end{array}\right\}\\
\quad \text{else return `not unifiable'};\\
\}
\end{array}
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while $|E| > 1$ {
  $D :=$ disagreement set of E;
  if D contains an X and a term t not containing X {
    $E := E[X/t]$;
    $\sigma := \sigma \cdot [X/t]$; }
  else return 'not unifiable';
}

- Example $E = \{f(f(Y), b), f(X, Y)\}$. Then $D = \{f(Y), X\}$ and we can replace X by $f(Y)$. E becomes $\{f(f(Y), b), f(f(Y), Y)\}$.
- The new disagreement is $D = \{b, Y\}$. After replacing $E[Y/b] = \{f(f(b), b)\}$ and the algorithm stops $\sigma = [X/f(Y)][Y/b]$.

Lists

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  list(1,list(2,list(3,list(4,null))))
  ```

- Prolog has a predefined operator `'[|]'/2` and a predefined constant `[]` so that a term like

  ```
  '[|]'(1,'[|]'(2,'[|]'(3,'[|]'(4,[]))))
  ```

  can be simply abbreviated as `[1,2,3,4]`

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member(X,[_Y|L]) :- member(X,L).
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```

- Try these queries:

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

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append([X|L1],L2,[X|L3]):-append(L1,L2,L3).
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- Use `append` to find the prefix `P` and suffix `S` of a given element `X` in a list `L`. For instance, with `X=wed` and `L=[sun,mon,tue,wed,thu,fri,sat]`, we should get `P=[sun,mon,tue]` and `S=[thu,fri,sat]`.

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- In the same list, find the predecessor and successor weekdays to some day `X`.

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4. *Use previous predicates to define* `perm(L,L2)` *so that* `L2` *is an arbitrary permutation of* `L`*.*

5. *Define predicate* `flatten(L1,L2)` *that removes nested lists putting all constants at a same level in a single list. Example:*

```
?- flatten([[a,b],[c,[d]]],L2).
L2 = [a,b,c,d]
```

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The cut predicate

- The cut predicate written `!` behaves as follows:

$$H :- \ B_1, \ldots, B_n, !, B_{n+1}, \ldots, B_m.$$

When `!` is reached, it succeeds but ignores any remaining choice for $B_1, \ldots, B_n$.

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- Example: the program

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max(X,Y,X) :- X>=Y.
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can be replaced by

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assuming that it is called with an unbounded third variable. Otherwise, a query `max(3,1,1)` will succeed.

The cut predicate

- This second alternative overcomes that problem

```
max(X,Y,M) :-
    X>=Y,!,M=X
  ;  M=Y.
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The cut predicate

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```
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```

- Another example:

```
p(1).
p(2) :- !.
p(3).
```

  try the queries

```
?- p(X).
?- p(X),p(Y).
?- p(3).
?- p(X),!,p(Y).
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```
add(X,L,L) :- member(X,L),!.
add(X,L,[X|L]).
```

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bird(a).  bird(b).  bird(c).  penguin(b).

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```

- Floundering problem: be careful with unbound variables inside negation. The query `?- fly(X).` will fail if using rule `fly(X) :- \+ penguin(X), bird(X).`

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- This means that anything that fails afterwards, will return to `repeat` forever.
- Its effect can only be canceled by a cut `!`

```
writelist(L) :-
  repeat, (member(X,L), write(X), fail; !).
```

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Arithmetics

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- We can make comparisons of numeric values using:
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- Examples:

```
gcd(X,X,X) :- !.
gcd(X,Y,D) :- X>Y,!,X1 is X-Y,gcd(X1,Y,D).
gcd(X,Y,D) :- X<Y,gcd(Y,X,D).

length([],0).
length([_|L],N):-length(L,M),N is M+1.
```

Arithmetics

Exercise 3

Define predicate `set_nth0(N,L1,X,L2)` *so that the element of list* `L1` *at position* `N` *(starting from 0) is replaced by* `X` *to produce list* `L2`.

Example:

```
?- set_nth0(3,[a,b,c,d,e,f],z,L2).
L2=[a,b,c,z,e,f].
```

Arithmetics

Exercise 4

We have a list of 9 elements that capture the content of a 3 × 3 grid. The positions in the list corresponds to the grid positions:

0	1	2
3	4	5
6	7	8

Define predicate `nextpos(X,D,Y)` *, so that* `Y` *is the adjacent position to* `X` *following direction* `D` *varying in* `{u,d,l,r}`*.*

Example:

```
?- nextpos(4,u,X).
X=1.
?- nextpos(4,l,X).
X=3.
```

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- `put(C)` puts character with code `C` in the standard output.
- `get0(C)` gets a character code from standard input. `get(C)` is similar but ignoring blank or non-printable characters.

Assert/retract

- We can modify the database of facts and rules in a dynamic way.
  - `assert(T)` includes new fact/rule `T`.
  - `asserta(T)` includes new fact/rule `T` in the beginning.
  - `assertz(T)` includes new fact/rule `T` in the end.
  - `retract(T)` retracts fact/rule `T`. It fails when not possible (the fact did not match to any existing one).
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- Some Prolog implementations require that predicates are declared as dynamic.

```
:- dynamic user/1.
user(1).
user(2).

?- asserta(user(0)).
?- user(X).
```

Assert/retract

We can use assert/retract to create a “global variable”

```
:- dynamic mycounter/1.

mycounter(0).

increment(X) :-
    retract(mycounter(C)),
    D is C+X,
    assert(mycounter(D)).

?- mycounter(C).
C=0.
?- increment(5), mycounter(C), increment(10).
C=5.
?- mycounter(C).
C=15.
```

Testing the type of terms

- `var(X)` true when `X` is an uninstantiated variable
- `nonvar(X)` true when `X` is not a variable or is already instantiated
- `atom(X)` true when `X` is a symbolic atom
- `integer(X)` true when `X` is an integer number
- `float(X)` true when `X` is a floating point number
- `number(X)` true when `X` is a numeric atom (either integer or float)
- `atomic(X)` true when `X` is atomic (either atom or number)

Dealing with atoms and strings

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Dealing with atoms and strings

- Symbolic atoms can contain special characters by using simple quote: `mother('Juana la Loca','Carlos I').`
- The use of double quotes `"Carlos I"` stands for a list of ASCII codes `[67, 97, 114, 108, 111, 115, 32, 73]`.
- `name(A,L)` transforms atom `A` into a list of ASCII codes or vice versa. Examples:

```
?- name('Carlos I',L).

L = [67, 97, 114, 108, 111, 115, 32, 73]

?- append("Hello ","World !",L),name(A,L).

L = [72, 101, 108, 108, 111, 32, 87, 111,
114|...],
A = 'Hello World !'
```

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- Any ASCII code for a character *c* can be retrieved by using `0'`*c*. For instance:

```
?- name(A,[ 0'a,0'$,0'.,0'[ ]).

A = 'a$.['
```

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```
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A = 'a$.['
```

- `concat_atom(L,A)` concatenates a list of atoms into a new atom. Example:

```
?- concat_atom(['Hello ','World ','!'],A).

A = 'Hello World !'
```

Building terms

- The special equiality predicate `X =..L` unifies term `X` with a list `L=[F,A1,A2,...]` where `F` is the main functor of `X` and and `A1,A2,...` its arguments.

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L = [f, a, b]

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```

- Process a list of terms so that the numeric arguments of unary functors are increased in one.

```
process([],[]):-!.

process([X|Xs],[Y|Ys]):-
  X =..  [F,A], number(A),!, A1 is A+1,
  Y=..[F,A1], process(Xs,Ys).
process([X|Xs],[X|Ys]):- process(Xs,Ys).
```

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double(X,Y) :- Y is 2*X.
minus(X,Y) :- Y is -X.
map([],_,[]).
map([X|Xs],P,[Y|Ys]) :- call(P,X,Y), map(Xs,P,Ys).

?- map([1,3,6],double,L).
?- map([1,3,6],minus,L).
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?- map([1,3,6],minus,L).
```

- We can also use `=..` to build the term to be called:

```
map([],_,[]).
map([X|Xs],P,[Y|Ys]) :-
    T=..[P,X,Y], T, map(Xs,P,Ys).
```

Higher order predicates

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- Get a list with all the ancestors of leonor

```
?- findall( X, ancestor(X,leonor), L).
```

- Example: convert a list of elements `[a,b,c,d]` into a list of duplicated pairs

```
?- findall( (X,X), member(X,[a,b,c,d]), L).
```