

An introduction to Prolog

Pedro Cabalar

Department of Computer Science
University of Corunna, SPAIN

February 2, 2017

1 Prolog

2 Functions

3 Flow control

4 Other features

A first glimpse at Prolog

- **PROLOG** stands for “**PRO**gramming in **LOGic**” (originally in French “*PROgrammation en LOGique*”).

A first glimpse at Prolog

- PROLOG stands for “PROgramming in LOGic” (originally in French “*PROgrammation en LOGique*”).
- Well suited for symbolic, non-numeric computation. Good for dealing with objects and relations.

A first glimpse at Prolog

- **PROLOG** stands for “**PRO**gramming in **LOGic**” (originally in French “*PROgrammation en LOGique*”).
- 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).

Typical example: family relationships

- Example: Juan Carlos is the father of Felipe, Cristina and Elena.

Typical example: family relationships

- Example: Juan Carlos is the father of Felipe, Cristina and Elena. This can be expressed by the following three facts:

```
father(juancarlos,felipe).
```

```
father(juancarlos,cristina).
```

```
father(juancarlos,elena).
```

Typical example: family relationships

- Example: Juan Carlos is the father of Felipe, Cristina and Elena. This can be expressed by the following three **facts**:

```
father(juancarlos,felipe) .  
father(juancarlos,cristina) .  
father(juancarlos,elena) .
```

Their mother is Sofia:

```
mother(sofia,felipe) .  
mother(sofia,cristina) .  
mother(sofia,elena) .
```


Typical example: family relationships

- Example: Juan Carlos is the father of Felipe, Cristina and Elena. This can be expressed by the following three **facts**:

```
father(juancarlos,felipe) .  
father(juancarlos,cristina) .  
father(juancarlos,elena) .
```

Their mother is Sofia:

```
mother(sofia,felipe) .  
mother(sofia,cristina) .  
mother(sofia,elena) .
```

Felipe and Letizia have two children:

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

Typical example: family relationships

- We can **query** these facts as a **relational data base**. Is Juan Carlos, Elena's father? Is he Sofia's father?

```
?- father(juancarlos,elena) .
```

```
?- father(juancarlos,sofia) .
```

Typical example: family relationships

- We can **query** these facts as a **relational data base**. Is Juan Carlos, Elena's father? Is he Sofia's father?

```
?- father(juancarlos,elena) .
```

```
?- father(juancarlos,sofia) .
```

- Queries may contain **variables** (identifiers beginning with capital letters).

Typical example: family relationships

- We can **query** these facts as a **relational data base**. Is Juan Carlos, Elena's father? Is he Sofia's father?

```
?- father(juancarlos,elena) .
```

```
?- father(juancarlos,sofia) .
```

- Queries may contain **variables** (identifiers beginning with capital letters). Solutions = **instantiations** of variables for which the answer is Yes.

Typical example: family relationships

- We can **query** these facts as a **relational data base**. Is Juan Carlos, Elena's father? Is he Sofia's father?

```
?- father(juancarlos,elena) .
```

```
?- father(juancarlos,sofia) .
```

- Queries may contain **variables** (identifiers beginning with capital letters). Solutions = **instantiations** of variables for which the answer is `Yes`.
- We type `';'` to find more answers or return to stop.

Typical example: family relationships

- We can **query** these facts as a **relational data base**. Is Juan Carlos, Elena's father? Is he Sofia's father?

```
?- father(juancarlos,elena).
```

```
?- father(juancarlos,sofia).
```

- Queries may contain **variables** (identifiers beginning with capital letters). Solutions = **instantiations** of variables for which the answer is Yes.
- We type ';' to find more answers or return to stop.
- What would these queries mean?

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

```
?- mother(sofia,X).
```

```
?- father(X,Y).
```

```
?- mother(X,Y), father(Y,leonor).
```

Typical example: family relationships

- We can **query** these facts as a **relational data base**. Is Juan Carlos, Elena's father? Is he Sofia's father?

```
?- father(juancarlos,elena).  
?- father(juancarlos,sofia).
```

- Queries may contain **variables** (identifiers beginning with capital letters). Solutions = **instantiations** of variables for which the answer is Yes.
- We type ';' to find more answers or return to stop.
- What would these queries mean?

```
?- father(X,leonor).  
?- mother(sofia,X).  
?- father(X,Y).  
?- mother(X,Y), father(Y,leonor).
```

- How would you check whether Cristina and Elena have the same father?

Typical example: family relationships

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

```
?- mother(X,Y) , father(Y,leonor) .
```

```
?- father(Y,leonor) , mother(X,Y) .
```

although their computation is different, as we will see later.

Typical example: family relationships

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

```
?- mother(X,Y), father(Y,leonor).
```

```
?- father(Y,leonor), mother(X,Y).
```

although their computation is different, as we will see later.

- Sometimes, a variable is irrelevant. We can use '_' to ignore its value in the answer. Example: is Felipe a father?

```
?- father(felipe,_).
```

Typical example: family relationships

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

```
?- mother(X,Y), father(Y,leonor).
```

```
?- father(Y,leonor), mother(X,Y).
```

although their computation is different, as we will see later.

- Sometimes, a variable is irrelevant. We can use '_' to ignore its value in the answer. Example: is Felipe a father?

```
?- father(felipe,_).
```

Who has a father and a mother?

Typical example: family relationships

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

```
?- mother(X,Y) , father(Y,leonor) .
```

```
?- father(Y,leonor) , mother(X,Y) .
```

although their computation is different, as we will see later.

- Sometimes, a variable is irrelevant. We can use '_' to ignore its value in the answer. Example: is Felipe a father?

```
?- father(felipe,_) .
```

Who has a father and a mother?

```
?- father(_,X) , mother(_,X) .
```

Typical example: family relationships

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

```
?- mother(X,Y) , father(Y,leonor) .
```

```
?- father(Y,leonor) , mother(X,Y) .
```

although their computation is different, as we will see later.

- Sometimes, a variable is irrelevant. We can use '_' to ignore its value in the answer. Example: is Felipe a father?

```
?- father(felipe,_) .
```

Who has a father and a mother?

```
?- father(_,X) , mother(_,X) .
```

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

Adding rules

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

```
?- mother(X,Y), father(Y,Z).
```

we can define a new predicate `grandmother` using:

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

Adding rules

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

```
?- mother(X,Y) , father(Y,Z) .
```

we can define a new predicate `grandmother` using:

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

Rule head Rule body

Adding rules

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

```
?- mother(X,Y) , father(Y,Z) .
```

we can define a new predicate `grandmother` using:

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

Rule head Rule body

- The ‘:-’ symbol is read as **if** or as a \leftarrow implication.

Adding rules

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

`?- mother(X,Y) , father(Y,Z) .`

we can define a new predicate `grandmother` using:

$$\underbrace{\text{grandmother}(X,Z)}_{\text{Rule head}} \text{ :- } \underbrace{\text{mother}(X,Y), \text{father}(Y,Z)}_{\text{Rule body}} .$$

- The ‘:-’ symbol is read as **if** or as a \leftarrow implication.
- In first order logic, we would write:

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

Adding rules

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

```
?- mother(X,Y) , father(Y,Z) .
```

we can define a new predicate `grandmother` using:

$\underbrace{\text{grandmother}(X,Z)}_{\text{Rule head}} \text{ :- } \underbrace{\text{mother}(X,Y), \text{father}(Y,Z)}_{\text{Rule body}} .$

- The ‘:-’ symbol is read as **if** or as a \leftarrow implication.
- In first order logic, we would write:

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

- We can use it now in queries:

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

Adding rules

- 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.

Adding rules

- Another example: define the `parent` relation.

Adding rules

- Another example: define the `parent` relation.

```
parent(X,Y) :- father(X,Y) .  
parent(X,Y) :- mother(X,Y) .
```

Adding rules

- Another example: define the `parent` relation.

```
parent(X,Y) :- father(X,Y) .  
parent(X,Y) :- mother(X,Y) .
```

We can use disjunction ‘;’ for rules with same head

```
parent(X,Y) :- father(X,Y) ; mother(X,Y) .
```

Adding rules

- Another example: define the `parent` relation.

```
parent(X,Y) :- father(X,Y) .  
parent(X,Y) :- mother(X,Y) .
```

We can use disjunction ‘;’ for rules with same head

```
parent(X,Y) :- father(X,Y) ; mother(X,Y) .
```

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

Adding rules

- Some predicates never occur in rule heads, excepting facts. These are called **extensional**.

Adding rules

- Some predicates never occur in rule heads, excepting facts. These are called **extensional**.
- But of course, a predicate may **combine rules and facts**.

Adding rules

- Some predicates never occur in rule heads, excepting facts. These are called **extensional**.
- But of course, a predicate may **combine rules and facts**. For instance, predicate `female`, we may include some facts

```
female(cristina).  female(elena).  
female(leonor).   female(sofia2).
```

Adding rules

- Some predicates never occur in rule heads, excepting facts. These are called **extensional**.
- But of course, a predicate may **combine rules and facts**. For instance, predicate `female`, we may include some facts

```
female(cristina).  female(elena).  
female(leonor).   female(sofia2).
```

but we can also **derive it** from `mother`

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

Adding rules

- Exercise: define the `sister` relation.

Adding rules

- Exercise: define the `sister` relation.

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

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

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

Adding rules

- 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

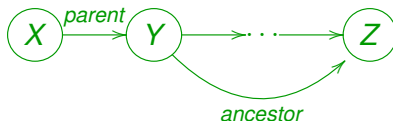
- Rules can be **recursive**, that is, a head predicate may also occur in the body.

Recursion

- Rules can be **recursive**, that is, a head predicate may also occur in the body.
- For instance, define the `ancestor` relation as the transitive closure of `parent`:

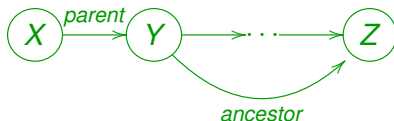
Recursion

- Rules can be **recursive**, that is, a head predicate may also occur in the body.
- For instance, define the `ancestor` relation as the transitive closure of `parent`:



Recursion

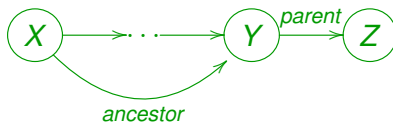
- Rules can be **recursive**, that is, a head predicate may also occur in the body.
- For instance, define the `ancestor` relation as the transitive closure of `parent`:



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

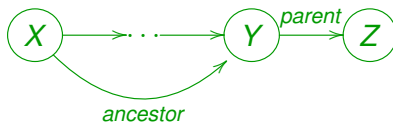
Recursion

- Another alternative can be:



Recursion

- Another alternative can be:

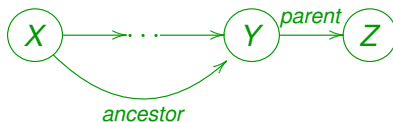


```
ancestor(X,Y) :- parent(X,Y) .
```

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

Recursion

- Another alternative can be:



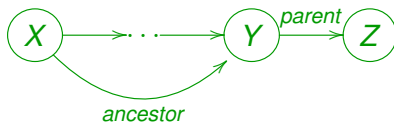
```
ancestor(X, Y) :- parent(X, Y) .  
ancestor(X, Z) :- parent(Y, Z), ancestor(X, Y) .
```

- In principle, this program is **equivalent** to:

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

Recursion

- Another alternative can be:



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

- In principle, this program is **equivalent** to:

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

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

Top-down goal satisfaction

- So, how does this **work**? Take

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

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

Top-down goal satisfaction

- So, how does this **work**? Take

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

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

- The query `?- ancestor(sofia,leonor) .` fixes a first **goal**.

Top-down goal satisfaction

- So, how does this **work**? Take

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

- The query `?- ancestor(sofia,leonor) .` fixes a first **goal**.
Prolog will look for rule heads that **match** the current goal.

Top-down goal satisfaction

- So, how does this **work**? Take

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

- The query `?- ancestor(sofia,leonor) .` fixes a first **goal**.
Prolog will look for rule heads that **match** the current goal.
- For instance, the first rule matches under the replacement
`X=sofia, Y=leonor`.

Top-down goal satisfaction

- So, how does this **work**? Take

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

- The query `?- ancestor(sofia,leonor)` fixes a first **goal**. Prolog will look for rule heads that **match** the current goal.
- For instance, the first rule matches under the replacement `X=sofia, Y=leonor`. This is like having the rule instance:

```
ancestor(sofia,leonor) :- parent(sofia,leonor).
```

Top-down goal satisfaction

- So, how does this **work**? Take

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

- The query `?- ancestor(sofia,leonor)` fixes a first **goal**. Prolog will look for rule heads that **match** the current goal.
- For instance, the first rule matches under the replacement `X=sofia, Y=leonor`. This is like having the rule instance:

```
ancestor(sofia,leonor) :- parent(sofia,leonor).
```

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

Top-down goal satisfaction

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

```
parent(X, Y) :- father(X, Y) .  
parent(X, Y) :- mother(X, Y) .
```

Top-down goal satisfaction

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

```
parent(sofia, leonor) :- father(sofia, leonor).  
parent(X, Y) :- mother(X, Y).
```

- The first one matches, so our new goal becomes `father(sofia, leonor)`.

Top-down goal satisfaction

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

```
parent(sofia, leonor) :- father(sofia, leonor).  
parent(X, Y) :- mother(X, Y).
```

- The first one matches, so our new goal becomes `father(sofia, leonor)`.
- However, `father` is extensional (only facts), and this fact is not included in the program. So, our goal **fails**.

Top-down goal satisfaction

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

```
parent(sofia, leonor) :- father(sofia, leonor).  
parent(X, Y) :- mother(X, Y).
```

- The first one matches, so our new goal becomes `father(sofia, leonor)`.
- However, `father` is extensional (only facts), and this fact is not included in the program. So, our goal **fails**.
- A **failure implies backtracking** to the last matching, and looking for new matches.

Top-down goal satisfaction

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

```
parent(X, Y) :- father(X, Y). (failed)
parent(X, Y) :- mother(X, Y).
```

Top-down goal satisfaction

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

```
parent(X,Y) :- father(X,Y). (failed)
parent(sofia, leonor) :- mother(sofia, leonor).
```

- Our new goal becomes `mother(sofia, leonor)`.

Top-down goal satisfaction

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

```
parent(X,Y) :- father(X,Y). (failed)
parent(sofia, leonor) :- mother(sofia, leonor).
```

- Our new goal becomes `mother(sofia, leonor)`. But this also fails: `mother` is extensional and this is not a fact.

Top-down goal satisfaction

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

```
parent(X,Y) :- father(X,Y). (failed)
parent(sofia, leonor) :- mother(sofia, leonor).
```

- Our new goal becomes `mother(sofia, leonor)`. But this also fails: `mother` is extensional and this is not a fact.
- Now, `parent(sofia, leonor)` has failed in its turn. We **backtrack** to `ancestor(sofia, leonor)` looking for another matching head.

Top-down goal satisfaction

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

```
parent(X,Y) :- father(X,Y). (failed)
parent(sofia, leonor) :- mother(sofia, leonor).
```

- Our new goal becomes `mother(sofia, leonor)`. But this also fails: `mother` is extensional and this is not a fact.
- Now, `parent(sofia, leonor)` has failed in its turn. We **backtrack** to `ancestor(sofia, leonor)` looking for another matching head.

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

Top-down goal satisfaction

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

```
parent(X,Y) :- father(X,Y). (failed)
parent(sofia, leonor) :- mother(sofia, leonor).
```

- Our new goal becomes `mother(sofia, leonor)`. But this also fails: `mother` is extensional and this is not a fact.
- Now, `parent(sofia, leonor)` has failed in its turn. We **backtrack** to `ancestor(sofia, leonor)` looking for another matching head.

```
ancestor(sofia, leonor) :-
    parent(sofia, Y), ancestor(Y, leonor).
```

Top-down goal satisfaction

- Now we have a **list of goals** `parent(sofia,Y), ancestor(Y,leonor).`

Top-down goal satisfaction

- 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 $X' = \text{sofia}$, $Y' = Y$.

Top-down goal satisfaction

- 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.

Top-down goal satisfaction

- 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).

Top-down goal satisfaction

- 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.

Top-down goal satisfaction

- 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, _)).
```

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, _)).
```

- Predicate `>` is predefined for arithmetic values.

Y dice que '`>`' ya esta definido como un predicado, no nos interesa su implementación, solo trabajemos con el y para adelante

Nada, que '`>`' funciona como en cualquier otro lenguaje de programación

Adding functions

Some examples of queries:

- Which is Juan Carlos' date of birth?
`?- born(juancarlos, X) .`

Adding functions

Some examples of queries:

- Which is Juan Carlos' date of birth?

```
?- born(juancarlos, X) .
```

- Is Felipe older than Letizia?

```
?- born(felipe, X) , born(letizia, Y) , later(Y, X) .
```

Adding functions

Some examples of queries:

- Which is Juan Carlos' date of birth?

```
?- born(juancarlos, X) .
```

- Is Felipe older than Letizia?

```
?- born(felipe, X) , born(letizia, Y) , later(Y, X) .
```

- Find two people that were born in the same year

Adding functions

Some examples of queries:

- Which is Juan Carlos' date of birth?

```
?- born(juancarlos, X) .
```

- Is Felipe older than Letizia?

```
?- born(felipe, X), born(letizia, Y), later(Y, X) .
```

- Find two people that were born in the same year

```
?- born(X, f(_, _, Y)), born(Z, f(_, _, Y)), X \= Z .
```

Adding functions

Some examples of queries:

- Which is Juan Carlos' date of birth?

```
?- born(juancarlos, X) .
```

- Is Felipe older than Letizia?

```
?- born(felipe, X), born(letizia, Y), later(Y, X) .
```

- Find two people that were born in the same year

```
?- born(X, f(_, _, Y)), born(Z, f(_, _, Y)), X \= Z .
```

- Which is Sofia's birthday?

```
?- birthday(sofia, X) .
```

Adding functions

- Note that, in principle, **functions are not evaluated**. They are just a way to **build data structures**.

Adding functions

- Note that, in principle, **functions are not evaluated**. They are just a way to **build data structures**.
- We usually call them **functors**, and they are identified by their **name** and **arity** (number of arguments). In the example: $f/3$, $d/2$.

Adding functions

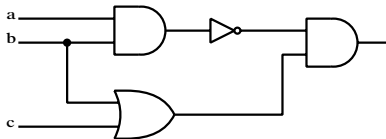
- Note that, in principle, **functions are not evaluated**. They are just a way to **build data structures**.
- We usually call them **functors**, and they are identified by their **name** and **arity** (number of arguments). In the example: $f/3$, $d/2$.
- We can use the same name for functors with **different arity**. For instance, we could have written:
`birthday(X, date(D,M)) :- born(X, date(D,M, _)) .`

Adding functions

- Note that, in principle, **functions are not evaluated**. They are just a way to **build data structures**.
- We usually call them **functors**, and they are identified by their **name** and **arity** (number of arguments). In the example: $f/3$, $d/2$.
- 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

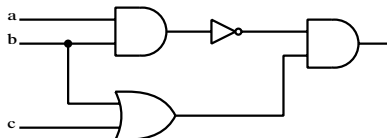
- Example: we can represent a digital circuit.



`and(not (and (a, b)), or (b, c))`

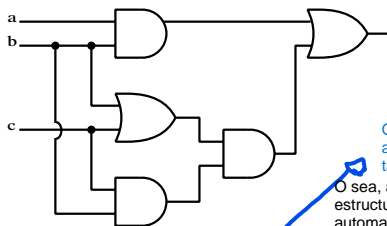
Adding functions

- Example: we can represent a digital circuit.



`and(not (and(a, b)), or(b, c))`

- Exercise: try to represent this circuit



Al evaluarlos son iguales, si, pero prolog los trata como estructuras distintas si el orden de los argumentos cambian

Que los operadores aritméticos son también funtores.



O sea, al hacer uso de ellos se crearan estructuras, pero no se evaluarán automáticamente, para poder evaluarlas se debe usar el operador 'is'

- 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, fyx, not) .`

`not (A & B) <==> not A v not B.`

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,fx,not) .`

`not (A & B) <==> not A v not B.`

- Try the following `?- F=(not a v b & c) , F=(H v G) .`

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.`

- 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

- How are functors handled in the goal satisfaction algorithm?

Unification

- How are functors handled in the goal satisfaction algorithm?
When searching a goal, we see whether it **matches** a rule head.

Unification

- How are functors handled in the goal satisfaction algorithm?
When searching a goal, we see whether it **matches** a rule head.
- 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.

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.
- 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:

```
 $\sigma := [];$   
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';  
}
```


Unification

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

```
 $\sigma := [];$   
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

- A list can be easily implemented with a functor. Take `list(X, L)` where `X` is the **head** and `L` is the **tail**. We could use `null` to represent an **empty list**.

Lists

- A list can be easily implemented with a functor. Take `list(X, L)` where `X` is the **head** and `L` is the **tail**. We could use `null` to represent an **empty list**.
- This is **not very readable**: `1, 2, 3, 4` would be represented as

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

Lists

- A list can be easily implemented with a functor. Take `list(X, L)` where `X` is the **head** and `L` is the **tail**. We could use `null` to represent an **empty list**.

- This is **not very readable**: `1, 2, 3, 4` would be represented as

```
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]`

Lists

- We can also write $' [\mid] '$ (X, L) as $[X \mid L]$.

Lists

- We can also write ' $[]$ ' (X, L) as $[X \mid L]$.
- Similarly, $[X, Y, Z \mid L]$ stands for $[X \mid [Y \mid [Z \mid L]]]$
- And $[X, Y, Z]$ stands for $[X, Y, Z \mid []]$

Lists

- We can also write ' [|] ' (X, L) as [X | L].
- Similarly, [X, Y, Z | L] stands for [X|[Y|[Z|L]]]
- And [X, Y, Z] stands for [X,Y,Z|[]]
- Try the query:
?- L=[1,2|[3]], L=[1|[2|[3|[]]]].

Lists

- We can also write ' `[]` ' `(X, L)` as `[X | L]`.
- Similarly, `[X, Y, Z | L]` stands for `[X|[Y|[Z|L]]]`
- And `[X, Y, Z]` stands for `[X,Y,Z|[]]`
- Try the query:
`?- L=[1,2|[3]], L=[1|[2|[3|[]]]]`.
- Program predicate `member(X, List)`

Lists

- We can also write ' `[]` ' `(X, L)` as `[X | L]`.
- Similarly, `[X, Y, Z | L]` stands for `[X|[Y|[Z|L]]]`
- And `[X, Y, Z]` stands for `[X,Y,Z|[]]`
- Try the query:
`?- L=[1,2|[3]], L=[1|[2|[3|[]]]]`.
- Program predicate `member(X, List)`

`member(X, [X|_L]) .`

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

Lists

- We can also write ' `[]` ' (X,L) as `[X | L]`.
- Similarly, `[X, Y, Z | L]` stands for `[X|[Y|[Z|L]]]`
- And `[X, Y, Z]` stands for `[X,Y,Z|[]]`

- Try the query:

```
?- L=[1,2|[3]], L=[1|[2|[3|[]]]].
```

- Program predicate `member(X,List)`

```
member(X, [X|_L]).
```

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

- Try these queries:

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

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

```
?- member(a,X).
```

Lists

- Program predicate `append(L1, L2, L3)`

Lists

- Program predicate `append(L1, L2, L3)`

```
append([], L, L) .
```

```
append([X|L1], L2, [X|L3]) :- append(L1, L2, L3) .
```

Lists

- Program predicate `append(L1, L2, L3)`

```
append([], L, L) .
```

```
append([X|L1], L2, [X|L3]) :- append(L1, L2, L3) .
```

- Try these queries:

```
?- append([a,b], [c,d,e], L) .
```

```
?- append([a,b], L, [a,b,c,d,e]) .
```

```
?- append(L1, L2, [a,b,c]) .
```

Lists

- Program predicate `append(L1, L2, L3)`

```
append([], L, L) .
```

```
append([X|L1], L2, [X|L3]) :- append(L1, L2, L3) .
```

- Try these queries:

```
?- append([a,b], [c,d,e], L) .
```

```
?- append([a,b], L, [a,b,c,d,e]) .
```

```
?- append(L1, L2, [a,b,c]) .
```

- 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]`.

Lists

- Program predicate `append(L1, L2, L3)`

```
append([], L, L) .
```

```
append([X|L1], L2, [X|L3]) :- append(L1, L2, L3) .
```

- Try these queries:

```
?- append([a,b], [c,d,e], L) .
```

```
?- append([a,b], L, [a,b,c,d,e]) .
```

```
?- append(L1, L2, [a,b,c]) .
```

- 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]`.

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

Exercise 2

- 1 Use `append/3` to define the predicate `sublist(S,L)` so that `S` is a sublist of `L`.

Lists

Exercise 2

- 1 Use `append/3` to define the predicate `sublist(S,L)` so that `S` is a sublist of `L`.
- 2 Use `append/3` to define the predicate `insert(X,L,L2)` so that `X` is arbitrarily inserted in `L` to produce `L2`.

Lists

Exercise 2

- 1 Use `append/3` to define the predicate `sublist(S,L)` so that `S` is a sublist of `L`.
- 2 Use `append/3` to define the predicate `insert(X,L,L2)` so that `X` is arbitrarily inserted in `L` to produce `L2`.
- 3 Use `append/3` to define the predicate `del(X,L,L2)` so that `X` is (arbitrarily) deleted from `L` to produce `L2`.

Lists

Exercise 2

- 1 Use `append/3` to define the predicate `sublist(S,L)` so that `S` is a sublist of `L`.
- 2 Use `append/3` to define the predicate `insert(X,L,L2)` so that `X` is arbitrarily inserted in `L` to produce `L2`.
- 3 Use `append/3` to define the predicate `del(X,L,L2)` so that `X` is (arbitrarily) deleted from `L` to produce `L2`.
- 4 Use previous predicates to define `perm(L,L2)` so that `L2` is an arbitrary permutation of `L`.

Lists

Exercise 2

- ① Use `append/3` to define the predicate `sublist(S,L)` so that *S* is a sublist of *L*.
- ② Use `append/3` to define the predicate `insert(X,L,L2)` so that *X* is arbitrarily inserted in *L* to produce *L2*.
- ③ Use `append/3` to define the predicate `del(X,L,L2)` so that *X* is (arbitrarily) deleted from *L* to produce *L2*.
- 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]
```

- 1 Prolog
- 2 Functions
- 3 Flow control**
- 4 Other features

The cut predicate

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

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

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

The cut predicate

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

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

*When **!** is reached, it succeeds but ignores any remaining choice for B_1, \dots, B_n .*

- Example: the program

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

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

can be replaced by

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

`max (X, Y, Y) .`

The cut predicate

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

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

*When **!** is reached, it succeeds but **ignores any remaining choice** for B_1, \dots, B_n .*

- Example: the program

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

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

can be replaced by

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

`max(X, Y, Y) .`

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.
```

The cut predicate

- This second alternative overcomes that problem

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

- Another example:

```
p (1) .
```

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

```
p (3) .
```

try the queries

```
?- p (X) .
```

```
?- p (X) , p (Y) .
```

```
?- p (3) .
```

```
?- p (X) , ! , p (Y) .
```

The cut predicate

- Typically, it improves efficiency but changes the ways in which a predicate can be used.

The cut predicate

- Typically, it improves efficiency but changes the ways in which a predicate can be used.
- In some cases, it is really **necessary** for a reasonable solution to a programming problem.

The cut predicate

- Typically, it improves efficiency but changes the ways in which a predicate can be used.
- In some cases, it is really **necessary** for a reasonable solution to a programming problem. Example: add a non-existing element as head of a list. If existing, leave the list untouched.

The cut predicate

- Typically, it improves efficiency but changes the ways in which a predicate can be used.
- In some cases, it is really **necessary** for a reasonable solution to a programming problem. Example: add a non-existing element as head of a list. If existing, leave the list untouched.

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

Negation as failure

- The `fail` predicate always fails. The `true` predicate always succeeds.

Negation as failure

- The `fail` predicate always fails. The `true` predicate always succeeds.
- **Negation as failure** \backslash^+ can be defined as:

```
(\+ P) :- P,!,fail  
        ; true.
```


Negation as failure

- The `fail` predicate always fails. The `true` predicate always succeeds.
- **Negation as failure** $\backslash+$ can be defined as:

```
(\+ P) :- P,!,fail  
        ; true.
```
- Example: all birds fly, excepting penguins.

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

```
fly(X) :- bird(X), \+ penguin(X).
```

Negation as failure

- The `fail` predicate always fails. The `true` predicate always succeeds.

- **Negation as failure** $\backslash+$ can be defined as:

```
(\+ P) :- P,!,fail  
        ; true.
```

- Example: all birds fly, excepting penguins.

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

```
fly(X) :- bird(X), \+ penguin(X).
```

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

Predicate `repeat`

- Predicate `repeat` always succeeds (like `true`) but provides an infinite number of choice points.

Predicate `repeat`

- Predicate `repeat` always succeeds (like `true`) but provides an infinite number of choice points.
- This means that anything that fails afterwards, will return to `repeat` forever.

Predicate `repeat`

- Predicate `repeat` always succeeds (like `true`) but provides an infinite number of choice points.
- 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; !).
```

- 1 Prolog
- 2 Functions
- 3 Flow control
- 4 Other features**

Arithmetics

- Predicate `is` evaluates an arithmetic expression. We can use:
+ - * / ** (power) // (integer division) mod (modulo).

Arithmetics

- Predicate `is` evaluates an arithmetic expression. We can use:
+ - * / ** (power) // (integer division) mod (modulo).
- We can make comparisons of numeric values using:
> < >= =< =:= =\=

Arithmetics

- Predicate `is` evaluates an arithmetic expression. We can use:
`+` `-` `*` `/` `**` (power) `//` (integer division) `mod` (modulo).

- We can make comparisons of numeric values using:

`>` `<` `>=` `=<` `==` `=\=`

- 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.
```

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.
```

Input/output

- `write(X)` writes a term on the standard output; `tab(N)` writes N spaces; `nl` writes a newline character.

Input/output

- `write(X)` writes a term on the standard output; `tab(N)` writes `N` spaces; `nl` writes a newline character.
- Reading a term from standard input `read(X)`. When the end of file is reached, `X` becomes the special term `end_of_file`.

Input/output

- `write(X)` writes a term on the standard output; `tab(N)` writes `N` spaces; `nl` writes a newline character.
- Reading a term from standard input `read(X)`. When the end of file is reached, `X` becomes the special term `end_of_file`.
- `see(Filename)` changes standard input to `Filename`. When finished, we invoke predicate `seen`.

Input/output

- `write(X)` writes a term on the standard output; `tab(N)` writes `N` spaces; `nl` writes a newline character.
- Reading a term from standard input `read(X)`. When the end of file is reached, `X` becomes the special term `end_of_file`.
- `see(Filename)` changes standard input to `Filename`. When finished, we invoke predicate `seen`.
- Similarly, `tell(Filename)` changes standard output to `Filename`. When finished, we invoke predicate `told`.

Input/output

- `write(X)` writes a term on the standard output; `tab(N)` writes `N` spaces; `nl` writes a newline character.
- Reading a term from standard input `read(X)`. When the end of file is reached, `X` becomes the special term `end_of_file`.
- `see(Filename)` changes standard input to `Filename`. When finished, we invoke predicate `seen`.
- Similarly, `tell(Filename)` changes standard output to `Filename`. When finished, we invoke predicate `told`.
- `put(C)` puts character with code `C` in the standard output.

Input/output

- `write(X)` writes a term on the standard output; `tab(N)` writes `N` spaces; `nl` writes a newline character.
- Reading a term from standard input `read(X)`. When the end of file is reached, `X` becomes the special term `end_of_file`.
- `see(Filename)` changes standard input to `Filename`. When finished, we invoke predicate `seen`.
- Similarly, `tell(Filename)` changes standard output to `Filename`. When finished, we invoke predicate `told`.
- `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).
 - ▶ `retractall(T)` like `retract` but retracts all matching facts or rules.

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).
 - ▶ `retractall(T)` like `retract` but retracts all matching facts or rules.
- 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

- Symbolic atoms can contain special characters by using simple **quote**: `mother('Juana la Loca','Carlos I').`

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]`.

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 !'
```


Dealing with atoms and strings

- 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$. ['
```

Dealing with atoms and strings

- 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$.['
```

- `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 equality predicate $X = . . L$ unifies term X with a list $L = [F, A1, A2, \dots]$ where F is the main functor of X and $A1, A2, \dots$ its arguments.

Building terms

- The special equality predicate $X =..L$ unifies term X with a list $L=[F,A1,A2,...]$ where F is the main functor of X and $A1,A2,...$ its arguments. Examples
?- $f(a,b) =.. L$.

$L = [f, a, b]$

Building terms

- The special equality predicate $X =..L$ unifies term X with a list $L=[F,A1,A2,...]$ where F is the main functor of X and $A1,A2,...$ its arguments. Examples
?- $f(a,b) =.. L.$

$L = [f, a, b]$

?- $T =.. [+ , 3, 4] .$

$T = 3+4$

Building terms

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

?- $f(a,b) =.. L.$

$L = [f, a, b]$

?- $T =.. [+ , 3, 4].$

$T = 3+4$

- 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).`

Higher order predicates

- Predicate `call` allows calling other predicates handled as arguments.

Higher order predicates

- Predicate `call` allows calling other predicates handled as arguments.
- Example: apply some function to a list of numbers

```
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).
```


Higher order predicates

- Predicate `call` allows calling other predicates handled as arguments.
- Example: apply some function to a list of numbers

```
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).
```

- 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

- Predicate `findall(T,G,L)` collects in list L all the instantiations for term T that satisfy goal G

Higher order predicates

- Predicate `findall(T,G,L)` collects in list `L` all the instantiations for term `T` that satisfy goal `G`

- 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) .
```