

## 3. tutorial in Prolog

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**Task 1:** Play with arithmetics! Prolog has “imperative-style” arithmetics using the keyword `is`. Read and understand the following examples:

```
?- X is 1 + 1.  
X = 2.  
  
?- N is 3 + 4, M is N * 3.  
N = 7,  
M = 21.  
  
?- M is N * 3, N is 3 + 4.  
ERROR: is/2: Arguments are not sufficiently instantiated  
  
?- A is 13 div 5, B is 13 mod 5.  
A = 2,  
B = 3.  
  
?- D is round(2 * cos(pi)).  
D = -2.
```

The `is` predicate does not solve equations, it merely evaluates expressions just like C or Java.

Make sure not to confuse “is” with unification “=”. Unification is purely syntactic, no arithmetics is evaluated:

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

**Task 2:** Implement `factorial` using the straightforward idea (without an accumulator):

1. When asked for  $N!$ , first obtain the factorial of  $N - 1$ .
2. Multiply it with  $N$  and return the result.

**Task 3:** Implement `factorial` using an *accumulator*.

1. Add a 3<sup>rd</sup> argument  $A$ , which is initialized to 1.
2. When asked for  $N!$ , multiply  $A$  with  $N$  and send it to the recursive call for  $(N - 1)!$ .
3. In the non-recursive clause, merely return the result.

*This implementation should somewhat resemble imperative programming. Do you agree?*

**Task 4:** Compare CPU time of both implementations. You should get a result which looks like follows:

```
?- time(factorial1(10000,_)).
% 20,001 inferences, 3.361 CPU in 3.922 seconds
true .

?- time(factorial2(10000,_,1)).
% 20,001 inferences, 0.198 CPU in 0.245 seconds
true .
```

Notice the  $\sim 17\times$  speedup!

**Do both of your factorials run equally fast?** Make sure that `fact2` has the recursive call as the very last subcall, just before the final “.”!

If you're interested in the magic of tail-call optimization (which applies not only to Prolog, but also to C, JavaScript, Scheme, LISP, Haskell...), Wikipedia has a good resource:

[https://en.wikipedia.org/wiki/Tail\\_call](https://en.wikipedia.org/wiki/Tail_call)

**Task 5:** Draw SLD trees for `factorial1(3,X)` and `factorial2(3,X,1)`. These 2 resources are very instructive:

[https://www.cpp.edu/~jrfisher/www/prolog\\_tutorial/3\\_2.html](https://www.cpp.edu/~jrfisher/www/prolog_tutorial/3_2.html)

<http://cs.union.edu/~striegnk/learn-prolog-now/html/node88.html>

**Task 6:** Study the cut operator “!”. Deduce the result of the following program and queries:

```
q(b).
q(c).

p(a).
p(X) :- q(X), !.
p(d).
```

Query	Your guess	True answer
?- p(X).		
?- p(a).		
?- p(b).		
?- p(c).		
?- p(d).		

**Not sure why it works the way it does?** Ask your teacher!

**Task 7 (optional):** Draw SLD trees for these queries.

**Task 8:** Make two definitions of  $\text{max}(X,Y,Z)$ , where  $Z$  is the maximum of  $\{X,Y\}$ . One with the cut and one without. Which is simpler? More effective?

**Task 9:** Compare these 2 implementations of `append`:

```
append([], B, B).
append([H|A], B, [H|AB]) :- append(A, B, AB).

appendCut([], B, B) :- !.
appendCut([H|A], B, [H|AB]) :- append(A, B, AB).
```

Find some query, where `append` behaves differently from `appendCut`.

Can you formulate the class of queries, on which the two predicates behave differently?

**Task 10:** Flatten a nested list:

```
?- my_flatten([[a,b], [], [c,[d,e],[f]]], X).
X = [a, b, c, d, e, f] .
```

You might be getting additional answers like `X = [a, b, c, d, e, f, [], []]` ; ... If you do, place the cut in your code!

**Task 11:** Take any predicate, no matter how complicated. Is there a place for a cut, which does not affect the predicate's behavior at all?

*Note: The answer can be formulated absolutely precisely!*

**Task 12 (optional):** Define your own `my_not(Goal)` that succeeds only if the `Goal` fails. You may need two predicates: `call(Goal)` which executes the `Goal` and `fail` which always fails.

**Task 13 (optional):** Consider the ordinary and a *not not* call: `pred(...)` vs. `not(not(pred(...)))`. What are the similarities and differences?

If you struggle, try replacing “pred” with unification “=”.

**Task 14 (optional):** In the assignment you have already encountered `X \= Y` which fails if `X` and `Y` can be unified. Now try defining your own implementation of `diff(X,Y)` with the same behavior. You may need `fail` which always fails.

**Task 15 (optional):** Write matrix multiplication `mat_prod`:

```
?- mat_prod([[1,2],[3,4]], [[0,1],[2,3]], X).  
X = [[4,7],[8,15]].
```

**Tip:** Define and use a helper predicate `column`:

```
?- column([[1,2,3],[4,5,6]], Col, Rest).  
Col = [1,4],  
Rest = [[2,3],[4,5]].
```

**Task 16 (optional):** Mathematicians usually encode natural numbers as follows: Zero is 0. If `X` is a natural number, then `s(X)` is also. For example, number 3 is `s(s(s(0)))`. Define `plus(...)`, `minus(...)` and `product(...)` using this representation.