

# Programming Paradigms

## Unit 10 — Advanced Concepts

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# Outline

- 1 Interactive Programs
- 2 Sorting
- 3 Mapping
- 4 Foundation, Strengths and Weaknesses

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- 1 **Interactive Programs**
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# Interactive Programs/1

- Interactive loops are implemented by `while` loops in conventional languages
- The following Prolog program reads and echos from the input until one of the words 'quit' or 'exit' is input

```
echo :- read(X), echo(X).  
echo(X) :- last_input(X), !.  
echo(X) :-  
    write(X), nl,  
    read(Y), !,  
    echo(Y).  
  
last_input(quit).  
last_input(exit).
```

- The predicate `read(X)` reads the next term from the input stream and matches it with X (must be followed by a '.', which is not part of the term)
- `read(X)` **succeeds only once**, i.e., no alternative choice upon backtracking

# Interactive Programs with `repeat/1`

- An alternative way to implement a read/echo loop is to use the built-in predicate `repeat/0`, which is implemented as follows:

```
repeat.
```

```
repeat :- repeat.
```

- If we put `repeat` in a goal, it **always succeeds** on backtracking
- This allows to transform goals/rules that have no choice into goals/rules that always succeed again on backtracking
- Examples are `read` and `write`, which have no choices

## Interactive Programs with repeat/2

- With repeat, the read/echo program looks as follows

```
echo2 :-  
    repeat,  
    read(X),  
    write(X),  
    nl,  
    ( X = 'quit' ; X = 'exit' ),  
    !.
```

- The operator ; specifies a **disjunction** of goals
  - X ; Y succeeds if at least one of the two X or Y succeeds
  - If X fails, then an attempt is made to satisfy Y
  - If Y fails, the entire disjunction fails
- Disjunction allows to express **alternatives** within the same clause
  - Can also be replaced by several facts and rules.
- It is advisable to put a disjunction into parentheses

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# Naïve Sorting

- A naïve way to sort a list  $L$  follows the generate and test pattern
  - Generate first a permutation  $S$  of the elements in  $L$
  - Test if the resulting list  $S$  is sorted

```
sort(L, S) :- permutation(L,S),
              sorted(S),
              !.
```

```
sorted([]).
sorted([X]).
sorted([X,Y|T]) :- X < Y,
                  sorted([Y|T]).
```

- This is not a very efficient way of sorting a list
- ... and we would have to write a different predicate for different sort orders
- Both issues will be addressed in the following

# Insertion Sort

- In the **insertion sort** method, each item of a list is considered one at a time and inserted into a new list in the appropriate position
- Predicate `insert(L,S)` succeeds when list *S* is a sorted version of list *L*

```
insert([], []).
insert([X|L], M) :-
    insert(L, N),
    insertx(X, N, M).
```

```
insertx(X, [A|L], [A|M]) :-
    A < X,
    !,
    insertx(X, L, M).
insertx(X, L, [X|L]).
```



# Constructing Structures

- A more **general-purpose insertion sorting** predicate is to pass the ordering predicate as an argument of `insort`, e.g.,
  - `insort([3,2,1], S, '<')` or
  - `insort([3,2,1], S, aless)`, where `aless` is self-defined order predicate
- In order to call the ordering predicate inside the sorting predicate, we need first to **construct a predicate**
- The predicate `=..` (also pronounced "**univ**") allows to construct a structure from a list of arguments
- The goal `P =.. L` means that `L` is the list consisting of the functor of the predicate `P` followed by its arguments

```
?- P =.. [foo, A, B, C].
```

```
P = foo(A,B,C)
```

```
yes
```

```
?- foo(a,b,c) =.. L.
```

```
L = [foo, a, b, c]
```

```
yes
```

# Generalized Insertion Sort/1

- Predicate `insortg(L,S,OrderPred)` succeeds when list `S` is a sorted version of list `L`, using the sort predicate `OrderPred`

```
insortg([], [], _).
insortg([X|L], M, O) :-
    insortg(L, N, O),
    insortgx(X, N, M, O).
```

```
insortgx(X, [A|L], [A|M], O) :-
    P =.. [O, A, X],
    call(P),
    !,
    insortgx(X, L, M, O).
insortgx(X, L, [X|L], _O).
```

- Predicate `call(P)` tries to prove `P` as a goal
  - Returns true if `P` can be satisfied, false otherwise

## Generalized Insertion Sort/2

- We can use `insortg` as follows

```
?- insortg([4,3,2,1], S, '<').
```

```
S = [1,2,3,4]
```

```
yes
```

```
?- insortg([4,3,2,1,5], S, '>').
```

```
S = [5,4,3,2,1]
```

```
yes
```

# Alphabetical Sorting/1

- For alphabetical sorting (or sorting more complex structures), we can write our own sorting predicates
- If we want to sort atoms, we need the predicate `name(A,L)` that relates atom A to the list L of character (ASCII codes) that make it up
  - i.e., name transforms atom A into a list L of characters or vice versa

```
?- name(apple, L).
```

```
L = [97,112,112,108,101].
```

```
?- name(A, [97,112,112,108,101]).
```

```
A = apple
```

```
?- name(apple, "apple")
```

```
true
```

```
?- name(apple, "pear")
```

```
false
```

## Alphabetical Sorting/2

- The following predicate `alless(X,Y)` implements alphabetical sorting
  - i.e., succeeds if `X` is alphabetically smaller than `Y`

```
alless(X, Y) :- name(X, XL),
                name(Y, YL),
                allessx(XL, YL).
```

```
allessx([], [_|_]).
```

```
allessx([X|_], [Y|_]) :- X < Y.
```

```
allessx([X|T1], [X|T2]) :- allessx(T1, T2).
```

- Now we can pass `alless` to the generalized insertion sort predicate

```
?- insortg([c,b,a], S, alless).
```

```
S = [a,b,c]
```

```
true
```

```
?- insortg([tom,joe,ann], S, alless).
```

```
S = [ann,joe,tom]
```

```
true
```

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# Mapping Lists/1

- **Mapping** one structure component-by-component to another structure is frequently needed, e.g., replace negative numbers in a list by zero
- The following predicate `maplist(P,L,M)` applies predicate `P` to each element in `L` to form a new list `M`

```
maplist(_, [], []) :- !.
maplist(P, [X|L], [Y|M]) :-
    Q =.. [P,X,Y],
    call(Q),
    maplist(P,L,M).
```

- To compute the absolute value  $|x|$  of a list of numbers, we need the following predicate

```
absolute(X,Y) :- X < 0, Y is X * -1, !.
absolute(X,X).
```

- `?- maplist(absolute, [2,-1,5,-10], L).`  
`L = [2,1,5,10]`  
`true`

## Mapping Lists/2

- The same predicate `maplist` can be used to implement a simple translation tool that translates a list of words/sentence into another language
- For that, we just need a dictionary

```
dict(the,le).
```

```
dict(chases,chasse).
```

```
dict(dog,chien).
```

```
dict(cat,chat).
```

- `?- maplist(dict, [the,dog,chases,the,cat], L).`  
`L = [le,chien,chasse,le,chat]`  
`true`

- **Example:** Write a predicate `maplist/4` that maps  $X \times Y \rightarrow Z$ .

## Applying a Predicate

- A simplification of `maplist` is `applist(P,L)`, which applies predicate `P` that is assumed to have one argument to all elements of list `L`

```
applist(_, []) :- !.  
applist(P, [X|L]) :-  
    Q =.. [P,X],  
    call(Q),  
    applist(P,L).
```

- The following will print each element of a list in a separate line

```
?- applist(writeln,[a,b,c]).  
a  
b  
c  
true.
```

# Mapping Structures/1

- Mapping is not restricted to lists, but can be defined for **any kind of structure**
- Consider arithmetic expression made up of '\*' and '+'
  - e.g.,  $3 + 4 * a + b$
- Suppose we want to remove multiplications by 1 and additions by 0
- The algebraic simplifications can be described by a predicate  $s(Op, La, Ra, Ans)$
- It represents that an expression consisting of an operator  $Op$  with left argument  $La$  and right argument  $Ra$  can be simplified to  $Ans$ 
  - e.g.,  $s(+, X, 0, X)$  represents that  $X + 0 = X$

## Mapping Structures/2

- The simplification rules are

```
s(+, X, 0, X).
```

```
s(+, 0, X, X).
```

```
s(+, X, Y, X+Y). /* catchall for + */
```

```
s(*, -, 0, 0).
```

```
s(*, 0, -, 0).
```

```
s(*, 1, X, X).
```

```
s(*, X, 1, X).
```

```
s(*, X, Y, X*Y). /* catchall for * */
```

- The "catchall" rules (at the end of each operator's part) are needed for the case that no simplification can be applied
  - This rule will always succeed, which is important when used in a mapping

## Mapping Structures/3

- With the above rules in place, we can write a simplification predicate that maps and simplifies arithmetic expressions

```
simplify(E, E) :- atomic(E), !.
simplify(E, F) :-
    E =.. [Op, La, Ra],
    simplify(La, X),
    simplify(Ra, Y),
    s(Op, X, Y, F), !.
```

- To simplify an expression E, we need first to simplify the left-hand argument of E, then the right-hand argument of E, then see if the simplified result can further be simplified
- `atomic(E)` succeeds if E is either an atom or an integer
- Simplifying expressions

```
?- simplify(a*10+(b+0+c)*1, S).
S = a * 10 + (b + c)
true
```

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# Mathematical Foundation

- Just a brief explanation how Prolog fits into the framework of mathematical logic
  - **First-order logic** is a powerful mathematical tool for formalizing descriptions
    - It is also sometimes called predicate logic
  - Unfortunately, first-order logic is not decidable
  - Prolog is based on a decidable subset of first-order logic called **Horn clauses**
  - It is still Turing-complete, though

# Strengths of Prolog

- Prolog is very well suited for application centered around **Artificial Intelligence (AI)**
  - Natural-language processing
  - AI behavior in games
  - Constraint satisfaction problems, such as time tabling and scheduling
- Prolog (or its descendants) is used in the context of the Semantic Web
  - A variant called **Datalog** is used in databases
- Also used for simulation and prediction software

# Weaknesses of Prolog

- Prolog has a **steeper learning curve** compared to other languages
- Fairly focused niche applications, not really a general-purpose language
- There are **scalability issues**, the basic matching strategy used by Prolog is **computationally expensive**
  - Has problems to process large data sets
- It is not as declarative as it seems at first glance
  - If you want to write efficient Prolog programs, you have to know what is going on behind the scenes

# Summary

- Prolog is a **declarative** programming language based on **First-order logic**
  - Specifies **what** to compute and not **how** to do it
- A Prolog program/knowledge base consists of **facts** and **rules**
- Evaluating a Prolog program means to prove a **goal**
  - Thereby, key concepts are **instantiation**, **matching**, and **backtracking**
- Prolog uses **recursion** instead of loops
- **Lists** and **structures** are two very important data structures
- The **cut** operator allows to stop backtracking
  - Should be used with care
  - A better programming style is to replace it by negation
- **“Generate and test”** is a very common programming pattern

# Summary

- The **box model** shows the execution of a Prolog program
  - Has four ports: CALL, EXIT, REDO, FAIL
- **Debugger** shows the program execution according to the box model
  - **trace** provides an exhaustive tracing mode
  - **debug** allows to jump to spy points set by the **spy** predicate
- **Accumulators** are frequently needed to collect intermediate results when traversing structures or lists
  - Helpful to make programs tail-recursive
- **Sorting** is an important operation
  - Generalized insertion sort, which allows to pass a sorting predicate
  - Constructing structures with the `=..` (univ) operator needed
- Another frequent and powerful operation is **mapping** structures and lists
  - General map-functions can be used
- **read** and **write** predicates for simple interactive programs