Part I

Logic programming: PROLOG

1 Introduction

What is Prolog?

Prolog is a programming language

The programmer *declares* a knowledge base (KB) and *asks* a question. Prolog does the rest.

The KB declared in Prolog is based on Horn's Clauses. To answer the question, Prolog uses Backward Chaining.

2 Syntax and Examples

Constants and Variables

Definition 1. A *Constant* is

1. Number: 12,3.5
2. Atoms:
   - any string that begins with a small letter
   - any string between " "
   - empty lists symbol []
3. Variables:
   - any string that begins with a capital letter
   - any string that begins with _
   - wildcard pattern _

Three kinds of knowledge

Definition 2. A *Fact* is a predicate. `p(...).` (i.e. $p(...)$). A fact can be seen as the *Head* of a Horn's clause.

Definition 3. A *Rule* is a complete Horn clause: `p(..) :- q(..), ..., r(..).` (i.e. $q(...) \wedge \cdots \wedge r(...) \Rightarrow p(...)$)

Definition 4. A *Query* is a set of predicates: `s(..),..,t(..).` A query can be seen as the *Body* of a Horn's clause.

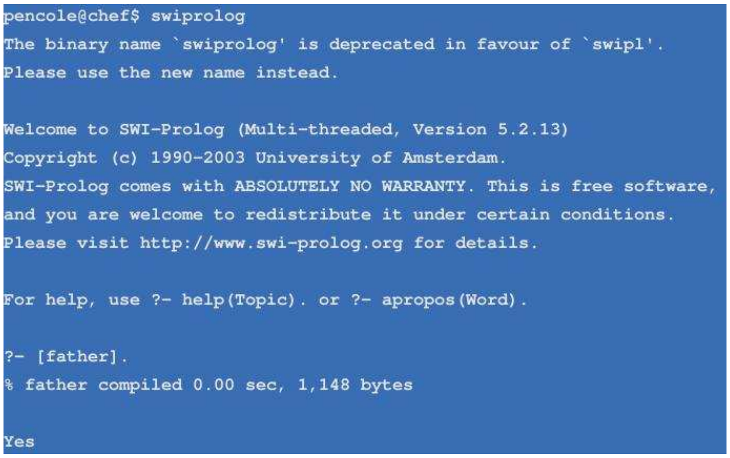
My first program

Here is the KB to program:

$father(charlie, david)$ $father(henri, charlie)$ $father(X, Z) \wedge father(Z, Y) \Rightarrow grandfather(X, Y)$

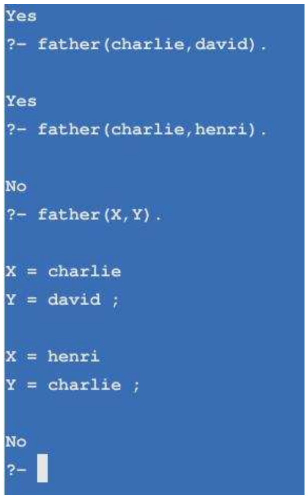
```
father(charlie,david).
  father(henri,charlie).
  grandfather(X,Y) :- father(X,Z) , father(Z,Y).
```

My first program



```
pencole@chef$ swiprolog
The binary name `swiprolog' is deprecated in favour of `swipl'.
Please use the new name instead.

Welcome to SWI-Prolog (Multi-threaded, Version 5.2.13)
Copyright (c) 1990-2003 University of Amsterdam.
SWI-Prolog comes with ABSOLUTELY NO WARRANTY. This is free software,
and you are welcome to redistribute it under certain conditions.
Please visit http://www.swi-prolog.org for details.

For help, use ?- help(Topic). or ?- apropos(Word).

?- [father].
% father compiled 0.00 sec, 1,148 bytes

Yes
```

My first program



```
Yes
?- father(charlie,david).

Yes
?- father(charlie,henri).

No
?- father(X,Y).

X = charlie
Y = david ;

X = henri
Y = charlie ;

No
?-
```

My first program

```
?- grandfather(x,y).

No
?- grandfather(X,Y).

X = henri
Y = david ;

No
?- grandfather(henri,X).

X = david ;

No
```

Order of the answers

```
?- listing.


mother(sophie, charlie).
mother(anne, david).


parents(A, B, C) :-
        father(B, A),
        mother(C, A).

%   Foreign: rl_read_init_file/1


father(charlie, david).
father(henri, charlie).
father(david, luc).
```

```
?- parents(X,Y,Z).

X = david
Y = charlie
Z = anne ;

X = charlie
Y = henri
Z = sophie ;

No
?-
```

Prolog “reads” clauses from the top to the bottom and “explores” from the left to the right.

Functions

In prolog, we can also declare a function of FOL. A function has not result, it is just a functional relation.

Example 5. John’wife: `wife(john)`

Such a term is always included in a predicate in prolog: `name(wife(john),marie).`

Be careful about the confusion between the function `wife(john)` which represents the wife of John and the predicate `wife(john)` which says that John is a wife!

Arithmetic

- Comparisons: `>, <, >=, =<, =:=, =\=`
- Assignation: `is`
  - `?- X is 3+2.`
  - `X=5`

- Predefined functions: `−, +, ∗,/, ˆ, mod, abs, min, max, sign, random, sqrt, sin, cos, tan, log, exp...`

Recursive programming

Depth-first search from a start state X: `dfs(X) :- goal(X).`

```
dfs(X) :- successor(X,S) dfs(S).
```

Factorial:

```
fact(A,B) :- fact(A,1,B). fact(A,B,C) :- A > 1, D is B*A, E is A-1, fact(E,D,C).
```

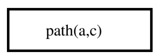
Redundant inference and infinite loops

```
link(a,b). link(b,c).   path(X,Z) :- link(X,Z). path(X,Z) :- path(X,Y), link(Y,Z).

link(a,b). link(b,c).   path(X,Z) :- path(X,Y), link(Y,Z). path(X,Z) :- link(X,Z).
```

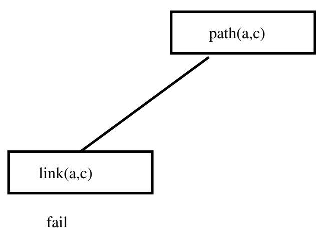
What is the difference between version 1 and version 2?

Proof tree: version 1

Example 6.

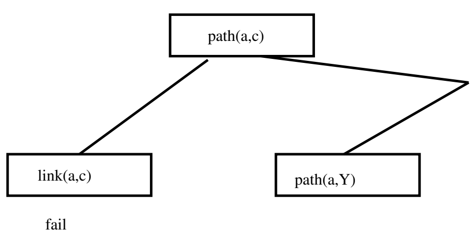


Proof tree: version 1



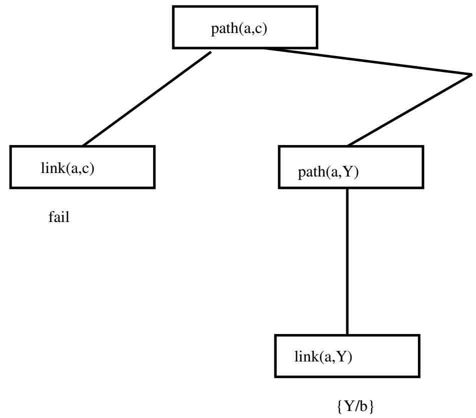
Example 7.

Proof tree: version 1



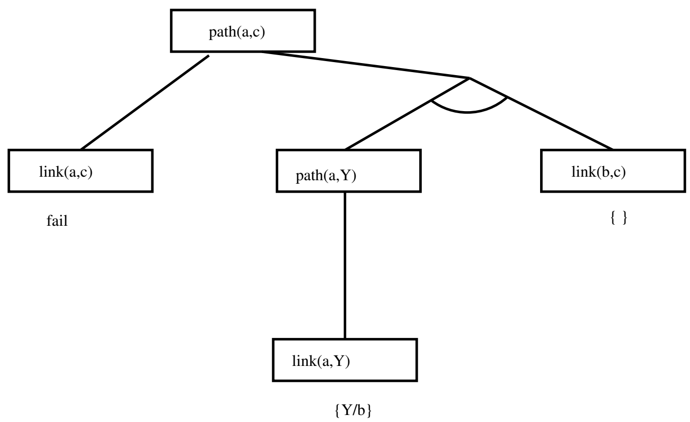
Example 8.

Proof tree: version 1



Example 9.

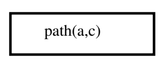
Proof tree: version 1



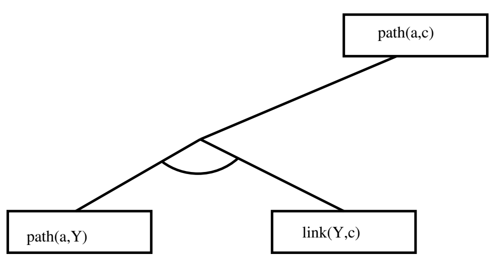
Example 10.

Proof tree: version 2

Example 11.

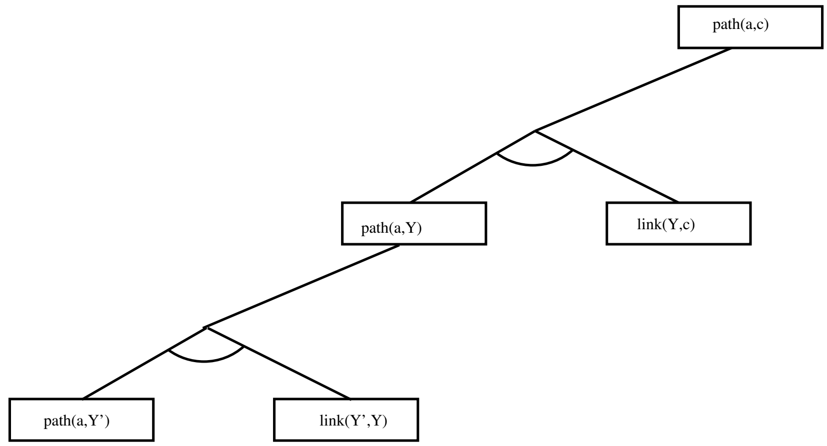


Proof tree: version 2



Example 12.

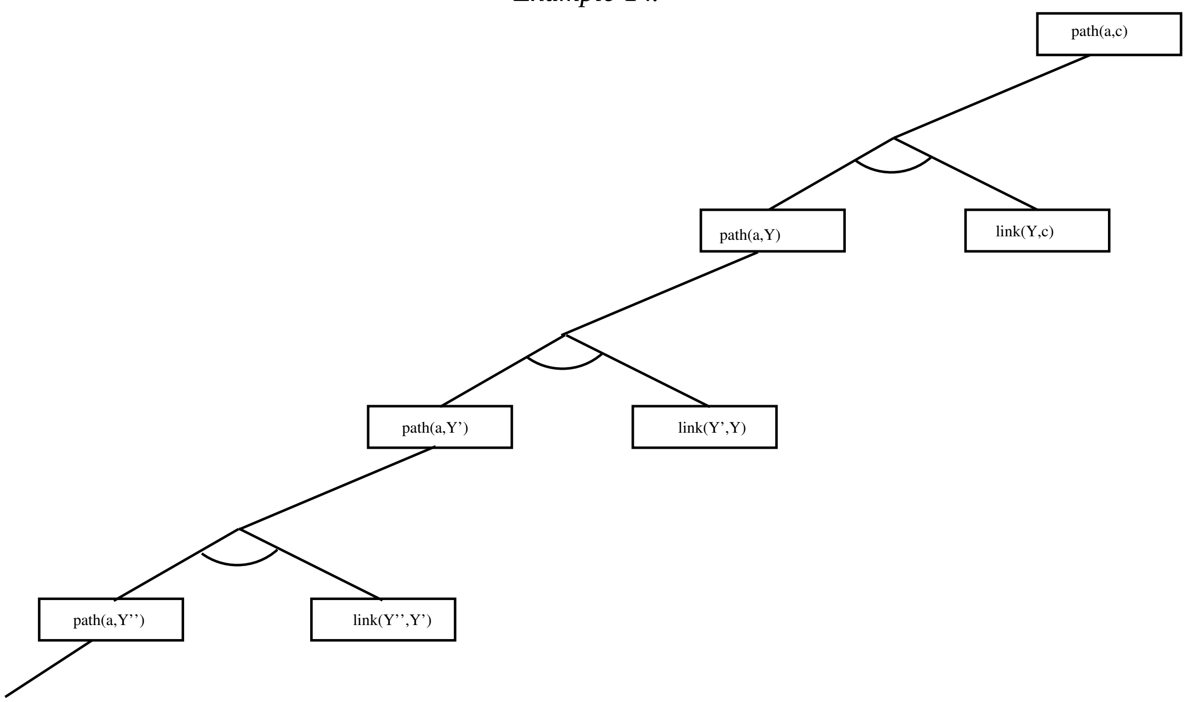
Proof tree: version 2



Example 13.

Proof tree: version 2

Example 14.



Term comparison and unification

- `T1 == T2` succeeds if T1 and T2 are *identical* (equality of FOL)
- `T1 \ == T2` succeeds if T1 and T2 are not identical

- `T1 = T2` is the *Unification* of T1 and T2 (i.e. UNIFY(T1,T2) is called)
- `T1 \= T2` succeeds if (i.e. UNIFY(T1,T2) has no solution)

Lists

The empty list is represented by: [ ]

A list has a *Head* and a *Tail*: [`Head` | `Tail`]

Example 15. The list a, b, c is denoted in Prolog: [`a` |[`b` |[`c` |[ ]]]]

Lists: examples

Example 16. 1. [`X` | `L`] `=` [`a, b, c`] →

Lists: examples

Example 17. 1. [`X` | `L`] `=` [`a, b, c`] → X = a, L = [b,c]

2. [`X` | `L`] `=` [a] →

Lists: examples

Example 18. 1. [`X` | `L`] `=` [`a, b, c`] → X = a, L = [b,c]

2. [`X` | `L`] `=` [a] → X = a, L =[ ]

3. [`X` | `L`] `=` [ ] →

Lists: examples

Example 19. 1. [`X` | `L`] `=` [`a, b, c`] → X = a, L = [b,c]

2. [`X` | `L`] `=` [a] → X = a, L =[ ]

3. [`X` | `L`] `=` [ ] → fail

4. [`X , Y`] `=` [`a,b,c`] →

Lists: examples

Example 20. 1. [`X` | `L`] `=` [`a, b, c`] → X = a, L = [b,c]

2. [`X` | `L`] `=` [a] → X = a, L =[ ]

3. [`X` | `L`] `=` [ ] → fail

4. [`X , Y`] `=` [`a,b,c`] → fail

5. [`X, Y` | `L`] `=` [`a,b,c`] →

Lists: examples

Example 21. 1. `[ X | L ] = [ a, b, c ]` → X = a, L = [b,c]

2. `[ X | L ] = [a]` → X = a, L =[ ]

3. `[ X | L ] = [ ]` → fail

4. `[ X , Y ] = [ a,b,c ]` → fail

5. `[ X, Y | L ] = [ a,b,c ]` → X = a, Y = b, L = [c]

6. `[ X | L ] = [ X,Y | L2 ]` →

Lists: examples

Example 22. 1. `[ X | L ] = [ a, b, c ]` → X = a, L = [b,c]

2. `[ X | L ] = [a]` → X = a, L =[ ]

3. `[ X | L ] = [ ]` → fail

4. `[ X , Y ] = [ a,b,c ]` → fail

5. `[ X, Y | L ] = [ a,b,c ]` → X = a, Y = b, L = [c]

6. `[ X | L ] = [ X,Y | L2 ]` → L = [Y|L2]

Sum of elements

Example 23. `sumElements([ ],0). sumElements([ A | B ], C) :-` `sumEl`
`is D+A.` Query:

```
?- sumElements([1,2,3,5],N). N = 11 ; No
```

Wildcard pattern: ith

Example 24. `ith([ X | _],1,X). ith([ _ | L ], R, Y) :- Rm1 is R-1, ith(L,Rm1,Y).`
Query:

```
?- ith([a,b,c,d],2,N). N = b ; No
```

Predicate append

`append` is a predefined predicate to append lists

Example 25. `?- append([a,b,c],[d,e],L) L = [ a,b,c,d ]` How to find the last element of a list? `?- append(_,[X],[a,b,c,d]) X`
`d` How to create sub-lists from lists? `?- append(L2,L3,[ b,c,a,d,e ]), append(L1, [ a ], L2). L2 =`
`[b,c,a] L3 = [d,e] L1 = [ b , c ]`

Sort

Example 26. Given two sorted lists L1, L2 the predicat `merge` merges the lists to build a new sorted list:

```
merge([ ], L, L).   merge( L, [ ], L).   merge( [X|L1], [Y | L2 ], [ X | L ]) :- X=<Y, merge(L1,
[ Y | L2 ], L).   merge( [X|L1], [Y | L2 ], [ Y | L ]) :- X>Y, merge([X | L1],L2, L).
```

Negation as failure

Prolog allows a "kind of" negation called *negation as failure*. If Prolog is not able to prove P then $notP$ is proved!

Example 27. `alive(X) :- not dead(X).`

means: "Everyone is alive if not provably dead".

Be careful the `not` is NOT the $\neg$ of FOL. If we are not able to prove $dead(X)$, we cannot say anything about $\neg dead(X)$

The cut

Imagine the following rules:

`R1: belong(X, [X | _ ]).` `R2: belong(X, [_| L ]) :- belong(X,L).`

and the query

`belong(X,[a,b,c]).` Solution: X = a, X = b, X = c **Proof tree**: at each node of the tree, we choose R1 and THEN R2.

`R1: belong(X, [X | _ ]):- ! .` `R2: belong(X, [_| L ]) :- belong(X,L).`

and the query `belong(X,[a,b,c]).` Solution: X = a **Proof tree**: We *cut* the complete proof tree. At each node of the tree, we choose only the rule that are before "!" (i.e. R1)

Last example :-)

```
person(yannick).
study(people,anu).
have(people,m1).
goodlectureslogic(m1).
students(X) :- study(X,anu).
gives(yannick,X,people) :- goodlectureslogic(X) , have(people,X).
goodteacher(X) :- person(X), gives(X,Y,Z), goodlecturesfol(Y) , students(Z).
goodlecturesfol(X) :- goodlectureslogic(X).
```

Query:

```
?- goodteacher(Yannick).
Yes
?- goodteacher(Z).
Z = Yannick
```