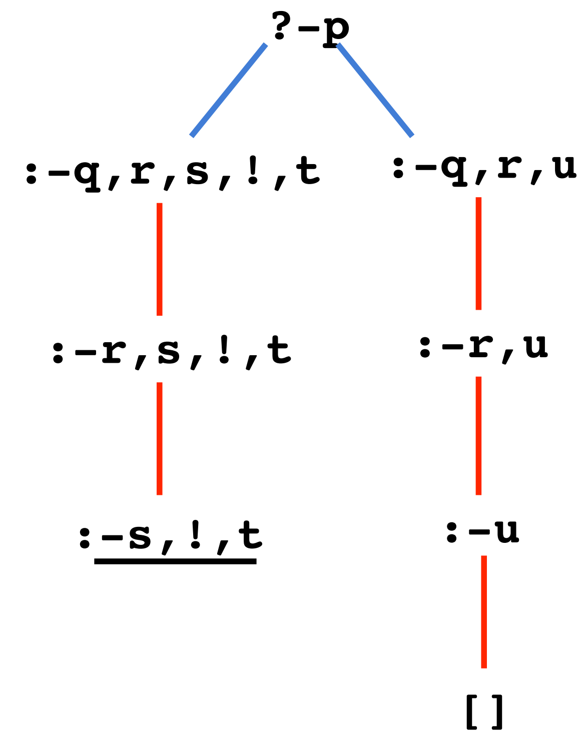
More uses of cut: *if-then-else*

q and r evaluated twice

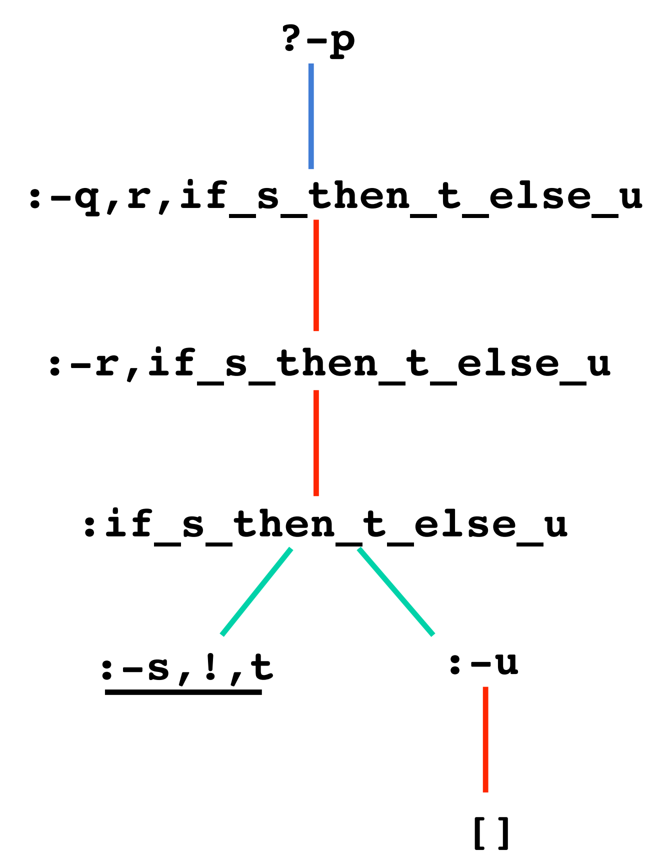
```
p:-q,r,s,!,t.
p:-q,r,u.
q.
r.
u.
```

only evaluated when s is false and both q and r are true



such uses are equivalent to

```
p:-q,r,if_s_then_t_else_u.
if_s_then_t_else_u:-s,!,t.
if_s_then_t_else_u:-u.
q.
r.
u.
```



More uses of cut: *if-then-else built-in*

```
p :- q,r,if_then_else(S,T,U).
if_then_else(S,T,U):- S,!,T.
if_then_else(S,T,U):- U.
```

built-in as `P->Q;R`

nested if's:
`P->Q;(R->S;T)`

```
diagnosis(Patient,Condition) :-
  temperature(Patient,T),
  ( T=<37       -> blood_pressure(Patient,Condition)
  ; T>37, T<38 -> Condition=ok
  ; otherwise  -> diagnose_fever(Patient,Condition)
```

always evaluates to true

More uses of cut: *enabling tail recursion optimization*

```
play(Board,Player):-
  lost(Board,Player).
play(Board,Player):-
  find_move(Board,Player,Move),
  make_move(Board,Move,NewBoard),
  next_player(Player,Next),!,
  play(NewBoard,Next).

:-play(starconfiguration,first).
```

would otherwise maintain all previous board configurations and all moves such that they can be undone

pops choice points from stack before entering next recursion

most Prolog's optimize tail recursion into iterative processes if the literals before the recursive call are deterministic

Arithmetic in Prolog: *is/2*

Peano-encoding of natural numbers is clumsy and inefficient

multiplication as repeated addition using recursion

```
?-X is 5+7-3.
X = 9
```

```
?-X is 5*3+7/2.
X = 18.5
```

```
?-9 is 5+7-3.
Yes
```

must be instantiated

```
?-9 is  X+7-3.
Error in arithmetic expression
```

defined as an infix operator

`is(Result,Expression)` succeeds if `Expression` can be evaluated as an arithmetic expression and its resulting value unifies with `Result`

Arithmetic in Prolog:

is/2 versus =/2

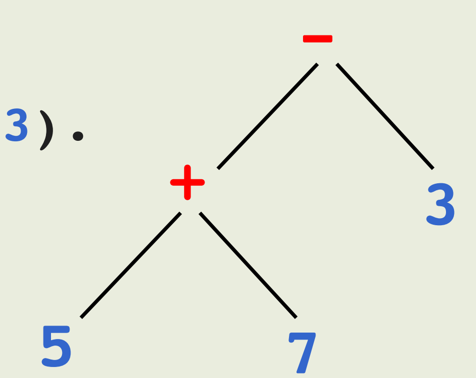
\=/2 when its arguments cannot be unified

succeeds if its arguments can be unified

```
?- X = 5+7-3
X = 5+7-3

?- 9 = 5+7-3
no

?- X = Y+3
X = _947+3
Y = _947

?- X = f(X)
X = f(f(f(f(f(f(f(f(f(f(f(f(f(f(f( ..
error: term being written is too deep
```

```
?-display(5+7-3).
-(+(5,7),3)
```

just a term



Prolog practices: accumulators

cannot simply place the recursive call after the is/2 literal as the latter's second argument has to be instantiated

not tail-recursive

```
length([],0).
length([H|T],N) :- length(T,N1), N is N1+1.
```

```
?-length([a,b,c],N)                 length([H|T],N1):-length(T,M1),
                                                       N1 is M1+1
                                    {H->a, T->[b,c], N1->N}
:-length([b,c],M1),                 length([H|T],N2):-length(T,M2),
  N is M1+1                                            N2 is M2+1
                                    {H->b, T->[c], N2->M1}
:-length([c],M2),                   length([H|T],N3):-length(T,M3),
  M1 is M2+1,                                          N3 is M3+1
  N is M1+1
                                    {H->c, T->[], N3->M2}
:-length([],M3),
  M2 is M3+1,                                length([],0)
  M1 is M2+1,
  N is M1+1
                                    {M3->0}
:-M2 is 0+1,
  M1 is M2+1,
  N is M1+1
        {M2->1}
:-M1 is 1+1,
  N is M1+1
        {M1->2}
:-N is 2+1
        {N->3}
[]
```

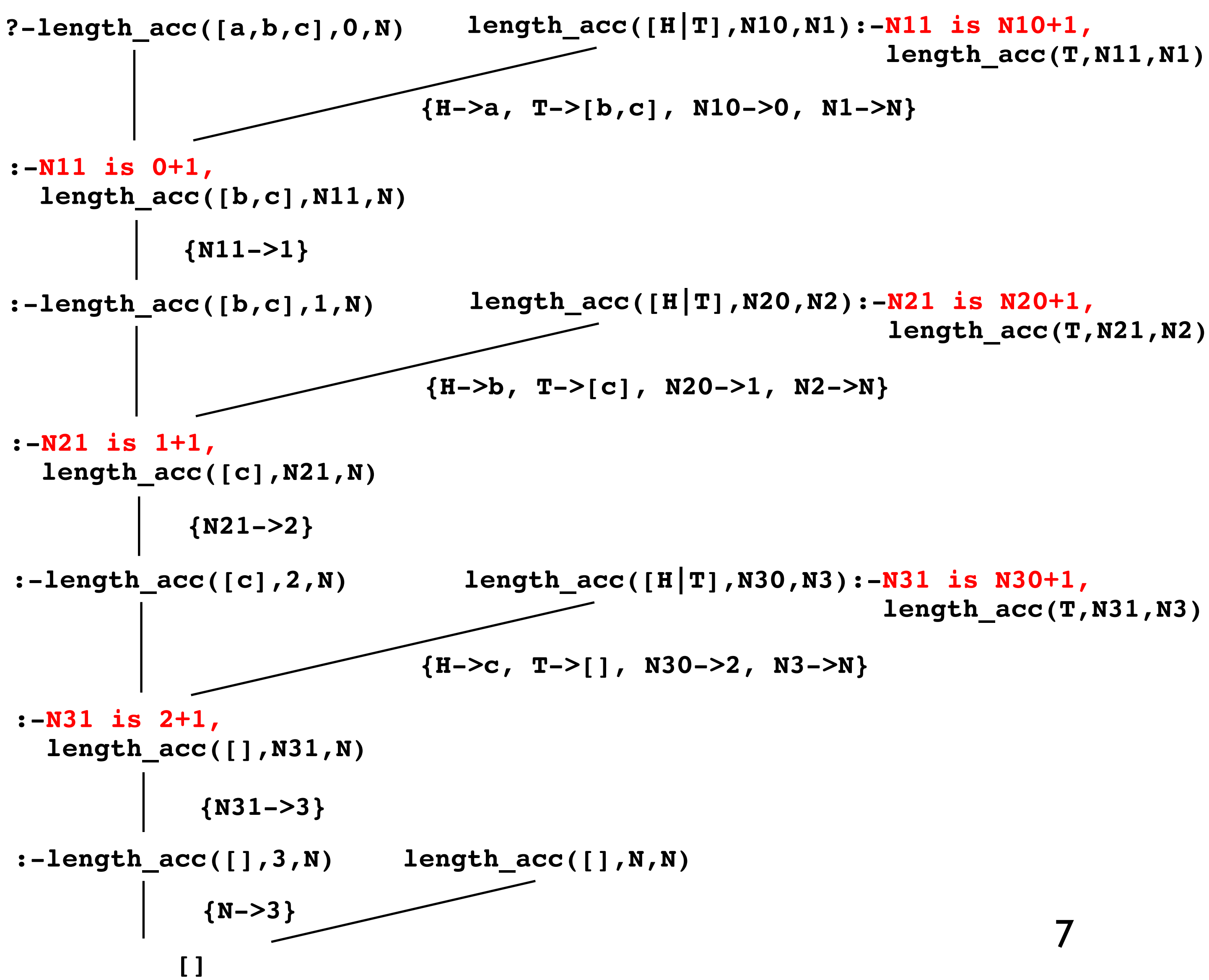
the resolvent collects as many is/2 literals as there are elements in the list before doing any actual calculation

Prolog practices: tail-recursive length/2 with accumulator

```
length(L,N) :- length_acc(L,0,N).
length_acc([],N,N).
length_acc([H|T],N0,N) :-
  N1 is N0+1,
  length_acc(T,N1,N).
```

accumulator represents length so far

read length_acc(L,M,N) as N = M + length(L)



Prolog practices:
tail-recursive reverse/2 with accumulator

```
naive_reverse([],[]).
naive_reverse([H|T],R) :-
  naive_reverse(T,R1),
  append(R1,[H],R).

append([],Y,Y).
append([H|T],Y,[H|Z]) :-
  append(T,Y,Z).
```

costly

reverse(X,Y,Z)
⇔ Z=reverse(X)+Y

```
reverse(X,Z) :- reverse(X,[],Z).

reverse([],Z,Z).
reverse([H|T],Y,Z) :-
  reverse(T,[H|Y],Z).
```

reverse(X,[],Z) ⇔ Z=reverse(X)

reverse([H|T],Y,Z) ⇔ Z=reverse([H|T])+Y

⇔ Z=reverse(T)+[H]+Y

⇔ Z=reverse(T)+[H|Y]

⇔ reverse(T,[H|Y],Z)

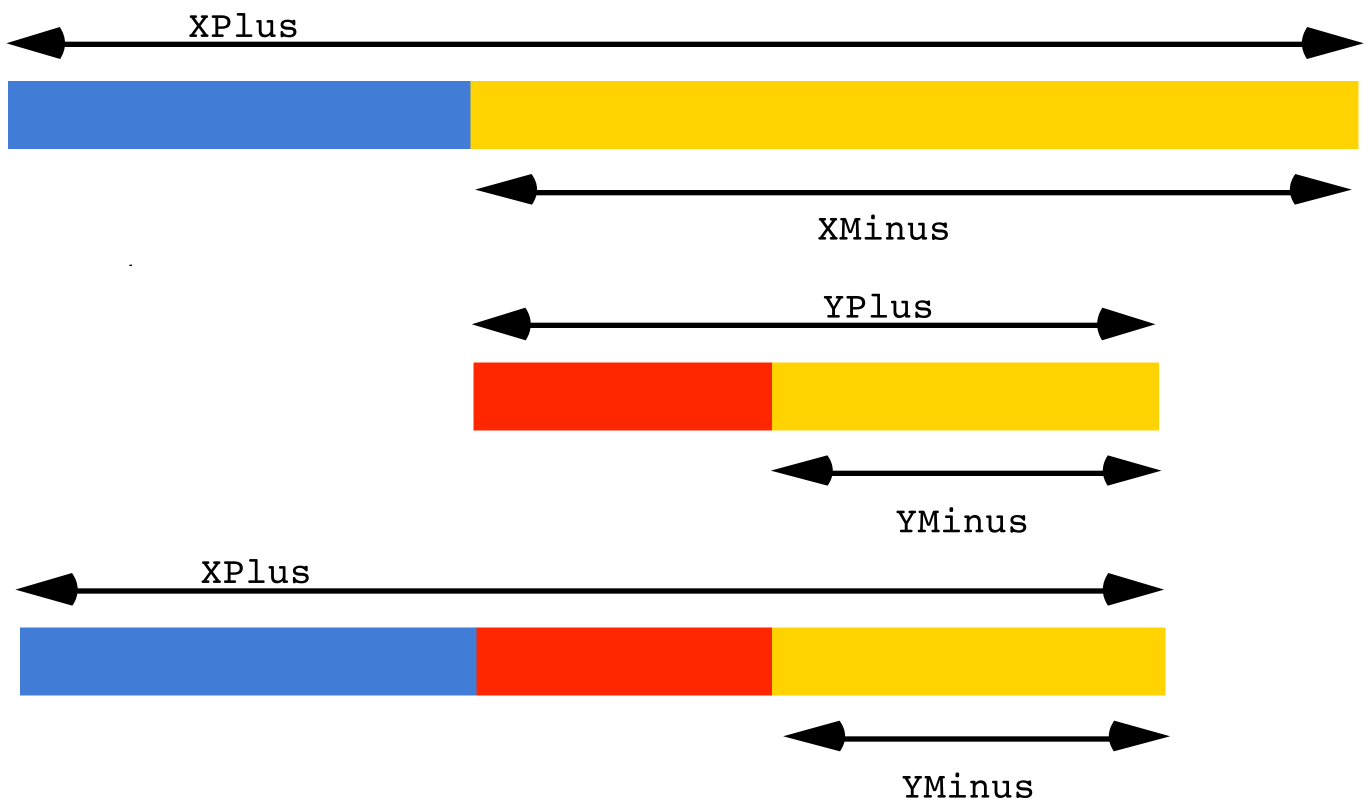
Prolog practices: difference lists

represent a list by a term L1-L2.

`[a,b,c,d]-[d]`	`[a,b,c]`
`[a,b,c,1,2]-[1,2]`	`[a,b,c]`
`[a,b,c|X]-X`	`[a,b,c]`

variable for minus list:
can be used as pointer to end of represented list

Prolog practices: appending difference lists in constant time



one unification step rather than as many resolution steps as there are elements in the list appended to

```
append_dl(XPlus-XMinus,YPlus-YMinus,XPlus-YMinus) :- XMinus=YPlus.
```

or

```
append_dl(XPlus-YPlus,YPlus-YMinus,XPlus-YMinus).

?-append_dl([a,b|X]-X,[c,d|Y]-Y,Z).
X = [c,d|Y], Z = [a,b,c,d|Y]-Y
```

Prolog practices: reversing difference lists

reverse(X,Y,Z) ⇔ Z=reverse(X)+Y

⇔ reverse(X)=Z-Y

reverse([H|T],Y,Z) ⇔ Z=reverse([H|T])+Y

⇔ Z=reverse(T)+[H|Y]

⇔ reverse(T)=Z-[H|Y]

```
reverse(X,Z) :- reverse_dl(X,Z-[]).

reverse_dl([],Z-Z).
reverse_dl([H|T],Z-Y) :- reverse_dl(T,Z-[H|Y]).
```

Second-order predicates: map/3

```
map(R, [], []).
map(R, [X|Xs], [Y|Ys]):-R(X,Y),map(R,Xs,Ys).
?-map(parent, [a,b,c],X)
```

or, when atoms with variable as predicate symbol are not allowed:

```
map(R, [], []).
map(R, [X|Xs], [Y|Ys]):- Goal =.. [R,X,Y],
                          call(Goal),
                          map(R,Xs,Ys).
```

Term=..List succeeds
if Term is a constant and List is the list [Term]
if Term is a compound term f(A1,..,An)
and List is a list with head f and whose tail unifies with [A1,..,An]

Second-order predicates: map/3

```
map(R, [], []).
map(R, [X|Xs], [Y|Ys]):-R(X,Y),map(R,Xs,Ys).
?-map(parent, [a,b,c],X)
```

or, when atoms with variable as predicate symbol are not allowed:

```
map(R, [], []).
map(R, [X|Xs], [Y|Ys]):- Goal =.. [R,X,Y],
                         call(Goal),
                         map(R,Xs,Ys).
```

univ operator =.. can be used to construct terms:
?-Term=..[parent,X,peter]
Term=parent(X,peter)

and decompose terms:
?-parent(maria,Y)=..List
List=[parent,maria,Y]

Term=..List succeeds
if Term is a constant and List is the list [Term]
if Term is a compound term f(A1,..,An)
and List is a list with head f and whose tail unifies with [A1,..,An]

Second-order predicates: findall/3

findall(Template,Goal,List) succeeds if List unifies with a list of the terms Template is instantiated to successively on backtracking over Goal. If Goal has no solutions, List has to unify with the empty list.

```
parent(john,peter).
parent(john,paul).
parent(john,mary).
parent(mick,davy).
parent(mick,dee).
parent(mick,dozy).
```

```
?-findall(C,parent(john,C),L).
  L = [peter,paul,mary]

?-findall(f(C),parent(john,C),L).
  L = [f(peter),f(paul),f(mary)]

?-findall(C,parent(P,C),L).
  L = [peter,paul,mary,davy,dee,dozy]
```

Second-order predicates: bagof/3 and setof/3

differ from findall/3 if Goal contains free variables

```
parent(john,peter).
parent(john,paul).
parent(john,mary).
parent(mick,davy).
parent(mick,dee).
parent(mick,dozy).
```

```
?-findall(C,parent(P,C),L).
  L = [peter,paul,mary,davy,dee,dozy]

?-bagof(C,parent(P,C),L).
  P = john
  L = [peter,paul,mary];

  P = mick
  L = [davy,dee,dozy]

?-bagof(C,P^parent(P,C),L).
   L = [peter,paul,mary,davy,dee,dozy]
```

a parent and its list of children

list of children for which a parent exists

The construct *Var^Goal* tells bagof/3 not to bind *Var* in *Goal*.

setof/3 is same as bagof/3 without duplicate elements in List

findall/3 is same as bagof/3 with all free variables existentially quantified using ^

Second-order predicates: assert/1 and retract/1

Backtracking over such literals will not undo the modifications to the database!

asserta(Clause)

    adds Clause at the beginning of the Prolog database.

assertz(Clause) and assert(Clause)

    adds Clause at the end of the Prolog database.

retract(Clause)

    removes first clause that unifies with Clause from the Prolog database.

retract all clauses of which the head unifies with Term

```
retractall(Term):-
retract(Term), fail.
retractall(Term):-
retract((Term:- Body)), fail.
retractall(Term).
```

failure-driven loop