# Introduction to Prolog

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# PROLOG

**A programming language based on the formalism and the concepts of formal logic.**

- PROgrammation LOGique
- Robinson (resolution)
- Kowalski (Logic Programming)
- Colmerauer & Roussel ( PROLOG )
- Warren DEC-10 (Quintus)
- I.C.O.T. PSI Engine
- 5th Generation

# Declarative programming

- ☞Concise Notation
- ☞Programming by specification
- ☞Constraints
- ☞DB Programming
  Facts and Rules

# LOGIC PROGRAMMING BASICS

## Terms

- relationship between objects

```
loves (peter,jane)
```

## Variables & functional expressions

```
loves (X, mother(jane))
```

## STATEMENTS

```
<head> :- <body> .
```

- RULES

```
bird(B) :- flies(B), lays_eggs(B).
```

- FACTS (*no body* )

```
flies (sparrow).
```

- QUERY (*no head )*

```
:- loves(X,peter) , girl(X).
```

1) Prove that there is someone who loves Peter and is a girl
2) Find values of X so that the **terms** in the query match **facts** in the database

# Facts

```
parent (john, robert) .
```

- relationship (predicate) : parent
- objects: John, Robert

*John is a parent of Robert*

- interpretation

*A parent of John is Robert. ? ? ?*

- Arity

```
2    parent (john, robert) .
1    man ( john ) .
3    loves ( graham , simula , madly ) .
0    hot .
```

- Relational programming

# Program

Set of Facts
Database

```
likes ( fred , susan) .
likes ( mary , fred) .
likes ( fred , beer ) .
likes ( susan , fred ) .
likes ( jack , mary) .

man (jack) .
man (fred) .

woman  (susan).
woman  (mary).

drink (beer) .
```

# Queries

- Is fred a man ?

```
:- man (fred) .
     => ok
```

==> Is **man(fred)** TRUE ?
==> Is the *fact* **man(fred)** in the database ?

## Goal to be proved

- Does Fred like Mary ?

```
:- likes (fred , mary ) .
     => no
```

- Conjunction of goals

```
:- likes ( fred , beer )  ,  man ( fred ) .
     => ok
```

# Variables

- An unspecified individual
- Denoted by initial Capital letter

  - Who likes Mary ?

  ==> Is there an X such **likes( X ,mary)** can be found in the DB ?

```
:- likes ( X , mary )  .
      => X = jack
```

- Multiple answers

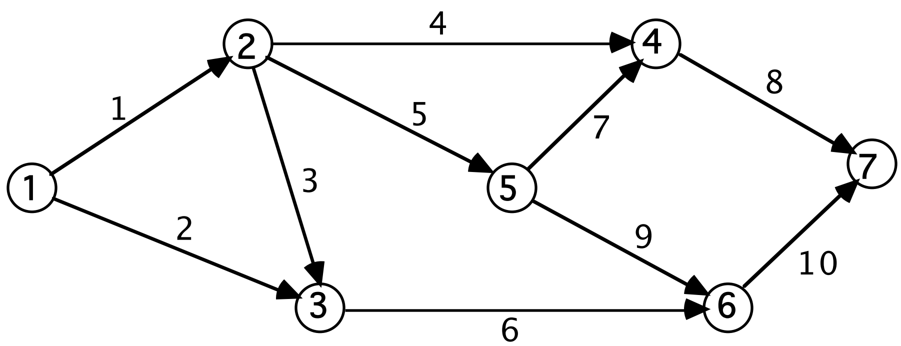
  - What does Fred like ?

```
:- likes ( fred , T ) .
  => T = susan ;
      T = beer
```

  - What girls does Fred like ?

```
:- likes ( fred , G ) , woman (G) .
  => G = susan
```

# PERT Example




**Prolog description**

arc ( Id, start-node, end-node, duration, resource)

```
arc (1,n1,n2,1,r1).
arc (2,n1,n3,4,r2).
arc (3,n2,n3,2,r3).
arc (4,n2,n4,3,r1).
arc (5,n2,n5,1,r2).
arc (6,n3,n6,4,r3).
arc (7,n5,n4,2,r1).
arc (8,n4,n7,3,r2).
arc (9,n5,n6,1,r3).
arc(10,n6,n7,4,r1).
```

# DATABASE PROGRAMMING

```
arc (1,n1,n2,1,r1).
arc (2,n1,n3,4,r2).
arc (3,n2,n3,2,r3).
arc (4,n2,n4,3,r1).
arc (5,n2,n5,1,r2).
arc (6,n3,n6,4,r3).
arc (7,n5,n4,2,r1).
arc (8,n4,n7,3,r2).
arc (9,n5,n6,1,r3).
arc(10,n6,n7,4,r1).
```

```
arc ( Id, start-node, end-node, duration, resource)
```

```
:- arc(4,n2,n4,_,_).              % Does arc4 link nodes 2 and 4 ?
    => OK

:- arc(6,_,_,D,R).                % What is the duration of activity 6
    => D=4, R=r3          %     and what resource does it use ?
```

Does activity 7 follows directly activity 5.

```
:- arc(5,_,N,_,_), arc(7,N,_,_,_).
    => N=5                  %  Yes, they meet at node 5.

:- arc(A,n5,_,_,_).               % What activities start at node 5 ?
    => A=7
       A=9
```

# PROLOG's Algorithm

$:-\ term_1, term_2, \ldots, term_n .$

equivalent to

```
for_all DB matches for term1 do
    for_all DB matches for term2 do
        . . . .
        for_all DB matches for termn do
            PRINT VALUES OF VARIABLES
            ( and optionally stop );
```

## BACKTRACKING

- When a term **fails**, Prolog uses another match for the previous term and tries again.

# Example

```
likes ( mary , fred) .
likes ( fred , susan) .
likes ( fred , beer ) .
likes ( susan , fred ) .
likes ( jack , mary) .

woman (susan).
woman (mary).
```

```
:- likes ( fred,G) , woman (G) .

likes ( mary , fred)
likes ( fred , susan) => woman(susan)
                         woman (susan)   ==> G=susan
                         woman (mary).

likes ( fred , beer ) => woman(beer)

                         woman (susan).
                         woman (mary).
likes ( susan , fred ) .
likes ( jack , mary) .
```

# Rules

Example:

```
bird (B) :- flies (B) , lays_eggs (B) .
```

<head> :- <tail>

1) *Head* is true IF *tail* is true
2) To prove *Head* , try to prove *tail*

Examples:

```
friends (A,B) :- likes (A,B) , likes (B,A).

person (P) :- woman (P) .
person (P) :- man (P) .

likes (M, mary) :- man (M) .
```

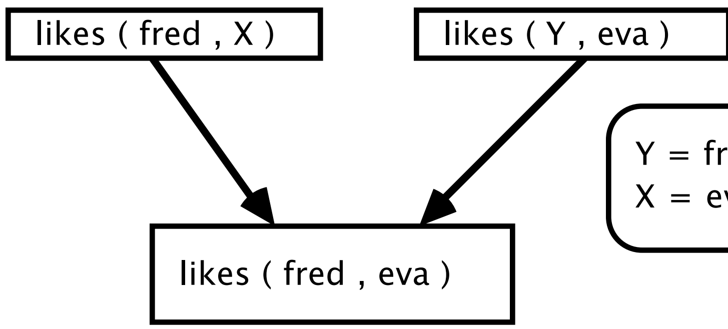
```
likes  (  mary  ,  fred)  .
likes  (  fred  ,  susan)  .
likes  (  fred  ,  beer  )  .
likes  (  susan  ,  fred  )  .
likes  (  jack  ,  mary)  .

woman  (susan).
woman  (mary).
```

```
:- friends (susan , F) .
 => F = fred

:- likes (F , mary) .
 => F = jack ;
    F = fred ;
    F = jack

:- person (X) .
 => X = susan ;
    X = mary ;
    X = jack;
    X = fred
```

# Unification

- Find constraints on variables so that 2 terms become identical

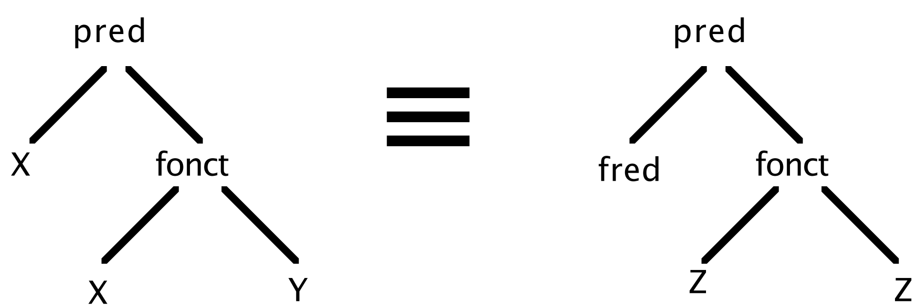
1




Y = fred
X = eva

2

pred (X, fonct (X,Y)) <==> pred (fred, fonct (Z,Z))




pred ( fred , fonct ( fred , fred) )

X = fred
X = Z
Z = Y

# Operators

## Infix Notation

- **1 + 2**
- **'+'(1,2)**

## Unary & Binary operators

- **op( 500 , yfx , + ) .**

  - Priority , arity, associativity

## Useful Operators

| | | |
|---|---|---|
| arithmetic: | **+ - * /** | |
| | **is :=** | *evaluable predicates* |
| comparison: | **> < =:=** | |

## Arithmetic

```
:-  X  is  4 + 5 ,  Y  is  ( X - 1 ) * 2 , 2 is 3-1.
      X = 9
      Y = 16
```

# "=" Equality ?

Unification operator

```
op ( 700 , xfx ,  =  ) .
= ( X , X) .


:-  f(1) = f(X) ,  =(Var,123) .
       X = 1
       Var = 123

:- X = 1 + 3 , Y is 1 + 3 .
       X = 1 + 3
       Y = 4
       A = 1

:- 4 = 1 + 3 .
       no.

:-  f (X , g( X , Y)) =  f (123 , g( Z , Z )) .
       X = 123
       Y = 123
       Z = 123

:-  A + 1  =  red + 1 .
       A = red
```

==

=

is

**:- X = 1 + 2 .**
X = 1 + 2

**:- X == 1 + 2 .**
no

**:- X  is  1 + 2 .**
X = 3

**:-  X = 1 ,  f ( 1 ) == f ( X ) .**
X = 1

**:-  X is  f ( 1 , 2 ) .**
no *or error*

# *Inequality*

| | |
|---|---|
| Not_unifiable | **\=** |
| Not Equal | **=:=** |
| Not Identical | **\==** |

```
:-  joe  \=  fred.
      ok

:-  X  \=  123  .
      no


:-  1 + 2  =:=  3  .
      no

:-  1 + 2  \==  3  .
      ok

:-  1 + 2  \=  3  .
      ok

:-  1 + 2  \=  X  .
      no
```

# Complex Unification

*(Zaniolo,,C. 1984  Object-oriented programming in Prolog)*

```
area( rect( H , W )  ,A)  :-  A is  H * W .
area( square (Side)  , A)  :-  area( rect(Side,Side), A)
.
area( triang (Side)  ,   A)  :-  A is  (H * W) / 2 .
```

**:- X = square(10) , area(X,Z) , write(area=Z) .**

```
area=100
ok
```

- selection of rule
- parameter passing
  - values in / out
- Note use of **=** to combine terms

# Input / Output

Prolog Terms

```
read (X)
write (X)
nl
```

Prolog syntax delimited by period

Characters

```
get  (C)
get0 (C)
put  (C)
```

Primitive but can be extended

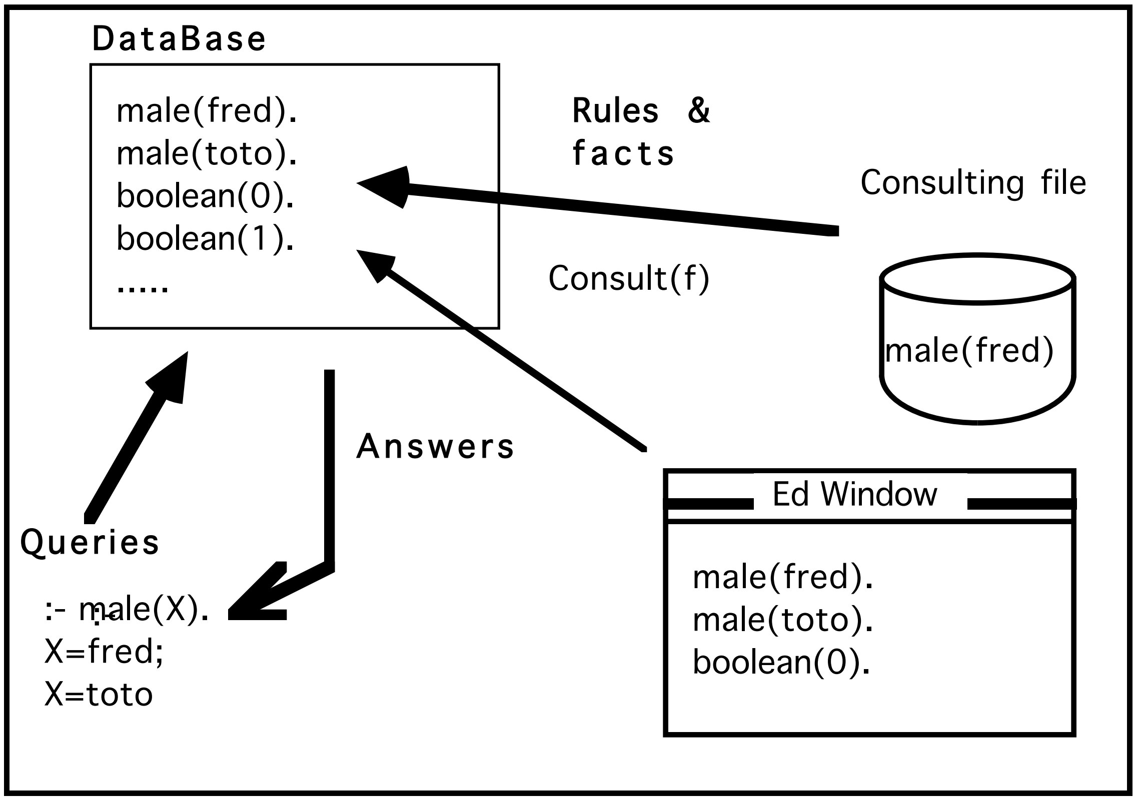
M-Prolog, Prolog II primitives

```
read_record(Str)
read_token(Token)
in-sentence(Sent,_)
```

```
:-    write('Input:  ') ,
      read(I),
      I2 is I+1,
      write(I2), nl .
```

```
Input:   123 .
124
ok
```

# Consulting and querying



# Assert & Retract

- To update the database during execution

```
:- male(X).
  X = fred ;
  X = toto

:- assert( male(john) ).

:- male(X).
  X = fred ;
  X = toto ;
  X = john

:- retract( male(toto) ).

:- male(X).
  X = fred ;
  X = john
```

- Asserta & assertz

# *Assignment*

## Pascal

```
Var x;
    x := 5;
    writeln (x);
    x := x+1;
```

## Prolog

```
assert(  value_of( x,5 ) ),
value_of( x,X ), writeln( X ),
retract( value_of( x,OldX )) ,
NewX  is OldX+1,
assert(  value_of( x,NewX   ) ).
```

# List Processing

# List Processing

Lists:

- Dynamic data structures
- Trees
- Graphs

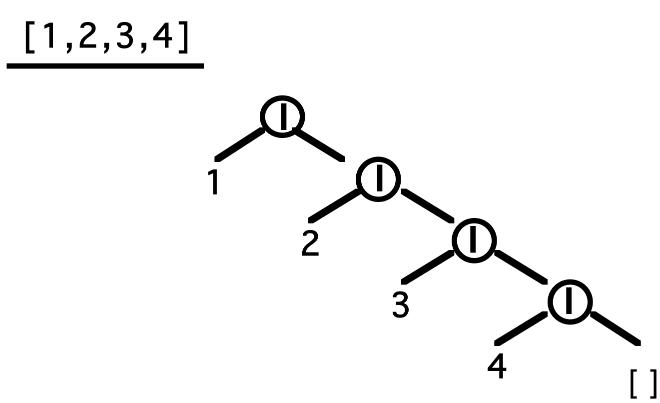
LISP: ( 1 2 3 4 )
nil
( 1 ((2) 3) 4 )

1) special symbol for empty list:
**nil or []**

2) binary nodes: **"|"** or **"."**

- Left = *first*
- Right = *rest of list*

PROLOG:

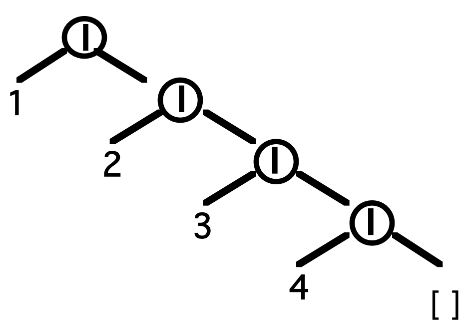


# *List Processing*

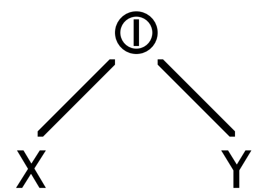
- Accessing elements
- Building lists

**[ 1,2,3,4 ] = [ X|Y ]**

[1,2,3,4]




[X|Y]




**=> X =1 , Y = [ 2,3,4 ]**

**:- [1,2,3 ] = [_,A| B] .**
**A = 2 , B =[3]**

# *Procedures for Lists*

## first (E,L)

E is the first element of the list L

```
first ( X , [X|_] ) .

:- first ( C , [red,white,blue] ) .
   C = red
```

## last (E,L)

E is the last element of the list L

```
last( X , [X] ) .
last( X , [_| Rest] ) :- last( X , Rest ) .

:- last ( C , [red,white,blue] ) .
   C = blue
```

## member( E,L )

E is a member of the list L

```
member ( X , [X|_] ) .
member ( X , [_| Rest] ) :- member( X , Rest ) .

:- member( red , [red,white,blue] ).
     ok
```

# *Using the Rules*

$\boxed{\text{member( E,L )}}$

```
member ( X , [X|_] ) .
member ( X , [_| Rest] ) :- member( X , Rest ) .
```

- Generator

```
:- member( X , [red,white,blue] ).
      X = red ;
                member( X , [white,blue])
      X = white ;
                member( X , [blue])
      X = blue
```

- Constraints

```
:- L = [_,_,_] , member( fred,L ), member (3,L),
      last(zzz,L) .

      L = [fred,3,zzz] ;
      L = [3,fred,zzz]
```

# Logic Black Holes

- infinite loops after a few good answers
- generators of elements of infinite set

    -i.e. lists

Example

```
:- member( 1 ,L ) , L = [X,X] .
   L = [1,1] ;
   L = [1,1] ;
   ..... infinite loop ...
```

The first term generates all lists of which "1" is a member:

[1], **[1,..], [–,1],** [–,1,..], [–,–,1], [–,–,–,1]... etc ...
  ^          ^

Only two are acceptable, but the generator keeps providing candidates for the second term to reject.

# APPEND

## Prototypical Example of DECLARATIVE PROGRAMMING

- Procedure with multiple uses

# *APPEND*

append (L1, L2, L3)

L3 is the result of concatenating L1 and L2

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

## Checking

```
append( [1,2] , [3] , [1,2,3] ).
      |                              by rule 2
append( [2] , [3] , [2,3] ).
      |                              by rule 2
append( [] , [3] , [3] ).
      |
  Proved by rule 1
```

# *APPEND*

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

- Concatenating lists

```
:- append( [a,b] , [c,d] , L) .
      L = [a,b,c,d]
```

- Spliting lists

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

      L1 = [] , L2 = [a,b,c]  ;
      L1 = [a] , L2 = [b,c]  ;
      L1 = [a,b] , L2 = [c]  ;
      L1 = [a,b,c] , L2 = []
```

## *APPEND*

- prefix( P,L ): P is a list of elements which prefix list L.

```
prefix( P,L ) :- append( P, _ , L).
```

- Sublist( S,L): S is a sublist of L

```
sublist( S,L ) :- prefix( P, L), append(_, S , P) .
```

- Naïve Reverse

```
reverse( [],[] ).
reverse( [X|Xs], Zs ) :-
    reverse( Xs,Ys), append( Ys, [X], Zs) .
```

# Permutations

- insert( E, L, L2 ): The list L2 is obtained by inserting E into the list L.

```
insert( E , [] , [E] ).
insert( E , [F|R] , [F|Rx] ) :- insert( E,R,Rx ).
```

- permute (L, Lp): The list Lp is a permutation of L

```
permute( [],[] ).
permute( [E|R], Lp) :-
     permute( R,Rp) , insert( E,Rp ).


:- permute( [ i, die, broke] , P ), writeln(P),fail.

     [i, die, broke]
     [die, i, broke]
     [die, broke, i]
     [i, broke, die]
     [broke, i, die]
     [broke, die, i]
```

# *CUT*

- Stops the combinatorial backtracking

```
:- term1, term2,     . . .  termn.

for  all  term1  do
     for  all  term2  do  ....   etc...
```

Examples:

```
max( A,B, M) :- A > B , M=A.
max( A,B, M) :- B>=A , M=B.
```

... , max(10,1,M), print(M), fail ...

```
M=10
M=1
```

or

```
digit(0).  digit(1).  ...   digit(9).
```

..., read(X), digit(X), ... fail ....

# *CUT (2)*

p ! or /

- within a clause prevents backtrack to goals to its left
- prevents use alternative clauses

CUT

```
f(...) :- .... ... .
f(...) :- .... , ... , ! , ... .
f(...) :- .... ... .
f(...) :- .... ... .
```

```
max(M, B, M) :- M<B, ! .
max(_, M, M) .          % else

one_of( P ) :- P , ! .

:- ... read(D) , one_of(digit(D)) , ...
```

# *Prolog and Logic Programming*

- Prolog is not Logic (programming)
    - Limited use of rules
    - Problems with
        - negative facts
        - disjunctive conclusions

**Modus ponens**

```
( A -> B )
& A        =>   B
```

**Modus tolens**

```
( A -> B )
& ¬ B           =>   ¬ A
```

Example:

1) Professors are poor
2) Paul is a professor
3) Peter is rich (not poor) (!!)

==>> Paul is poor
Peter is not a professor (!!)

4) Professors are devoted or crazy (!!)

# Implementations

## Edinburgh Prologs

DEC-10, C-Prolog
Quintus (speed champ ?)
BIM
Arity / AI Systems / Chalcedony (MAC / PC)
M-Prolog
Industrial strength

## Others

Prolog II (Apple II, VAX, MAC)
- different syntax - dif - freeze

Micro Prolog (LPA) early robust & fast Z80 -> IBM -> MAC
Borland's Turbo-Prolog (Type declarations)

## Parallelism & Object-Orientation

- Concurrent Prolog *parallelism*
- IC-Prolog, ParLog
- T-Prolog

- LOGLISP *Multiple languages*
- Smalltalk V

- POOPS, SIMPOOPS *Objects*

SIM ulation
P rolog
O bject
O riented
P rogramming
S ystem

- Natural integration
- Process Oriented Structure of SIMULA
- Knowledge manipulation of PROLOG
- Parallelism and Time

# Implementation

- 450 lines of Prolog
- built-in compiler

# *Single Server Queue*

```
class client (id);
methods
        seize(R)     :- wait(R,1).
        release(R)  :- send(R,1).
begin
        uniform(0,10,Ta),          hold(Ta),
        id(N), Nx is N+1, new_process (client, [id(Nx)] ),
                        write(N), writeln(" Waiting"),
        seize (res),
                        write(N), writeln(" Entering resource"),
        uniform(0,8,Ts),
        hold(Ts),
        release (res),
                        write(N), writeln (" Leaving system").
end

begin
        send(res,1),
        new_process( client, [id(1)] ),
        hold (20),
        writeln("Closing down system"),
        terminate.
end.
```

# Compiler Output

**CLASSES**

```
class(client)
class(main)
```

**CLASS PREDICATES**

```
class_predicate(client,seize)
class_predicate(client,release)
```

**OBJECT PREDICATES**

```
obj_pred(client,[id])
obj_pred(main,[])
```

**CLAUSES**

```
1: clauses(client,seize(_89),[wait(_89,1)],_90)
2: clauses(client,release(_81),[send(_81,1)],_82)
3: clauses(client, begin, [uniform(0,10,_70), hold(_70), id(_71),  _72 is   _71+1,
    new_process(client, [id(_72)]), write(_71), writeln( Waiting), seize(res),
    write(_71), writeln( Entering resource), uniform(0, 8,_73), hold(_73), release(res),
    write(_71), writeln( Leaving system)], _74)
4: clauses(main, begin, [send(res,1), new_process(client, [id(1)]), hold(20),
    writeln(Closing down system), terminate], _45)
```

# *Simple Queue Output*

```
1 Waiting
1 Entering resource
2 Waiting
3 Waiting
1 Leaving system
2 Entering resource
4 Waiting
2 Leaving system
3 Entering resource
3 Leaving system
4 Entering resource
Closing down system

*** THE END ***
CPU  : 0.95 sec
EVALS: 3779
FAILS: 453
```

# Conclusions

, Prolog - 5th Generation Language

, Declarative programming

, Power of Unification
    - pattern matching
    - rule selection

, No longer a research curiosity
    . Industrial language

, (SIM) POOPS : structured Prolog

, Knowledge and Processes

## Modelling for the future

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