Introduction
to
Prolog

Jean G. Vaucher
Incognito
Université de Montréal
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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
```

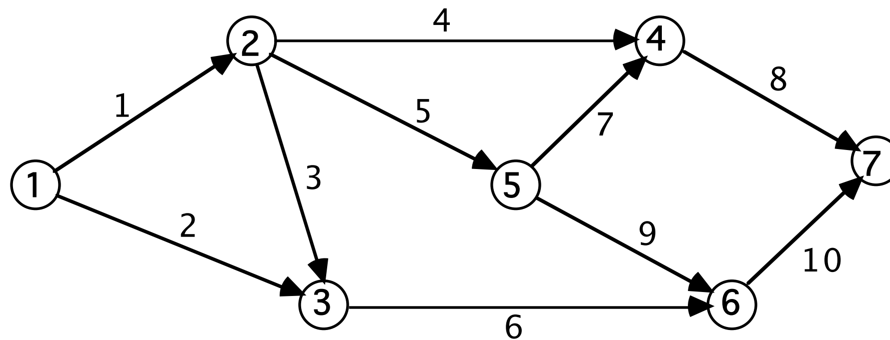
- Multiple answers
  - What does Fred like ?

```
:- 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

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

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:

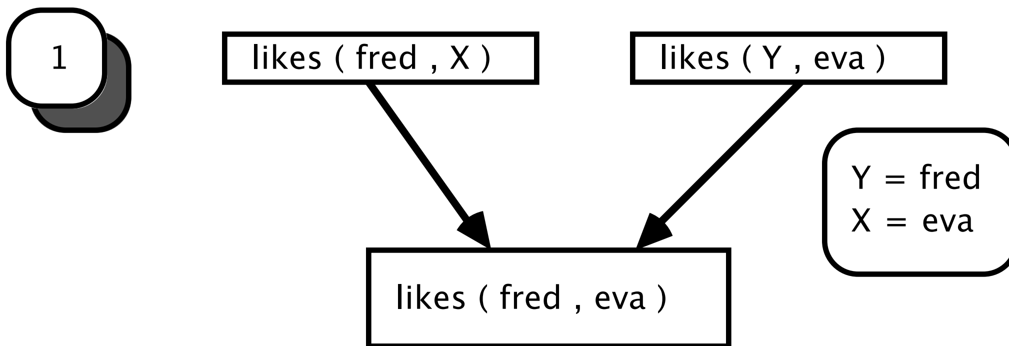
```
friends (A,B) :- likes (A,B) , likes (B,A).

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

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

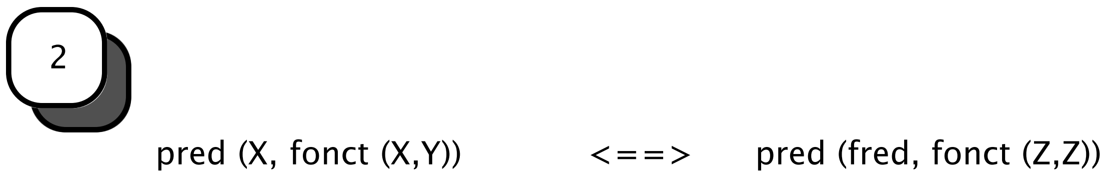
```
likes ( mary , fred) .
likes ( fred , susan) .
likes ( fred , beer ) .
likes ( susan , fred ) .
likes ( jack , mary) .

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

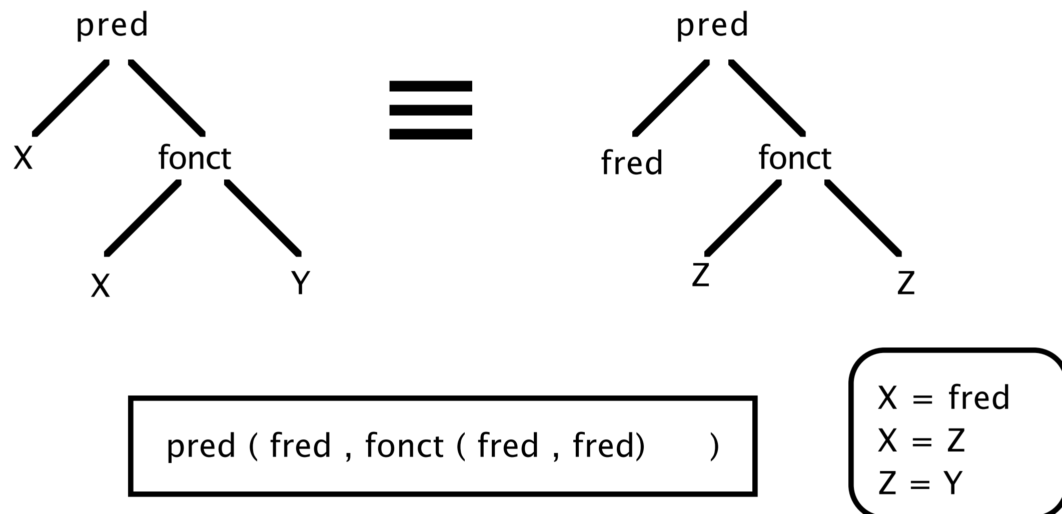
```
:- friends (susan , F) .
  => F = fred

:- 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







Operators

Infix Notation

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

Unary & Binary operators

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

  - Priority , arity, associativity

Useful Operators

arithmetic: **+ - * /**
is := *evaluable predicates*

comparison: **> < =:=**

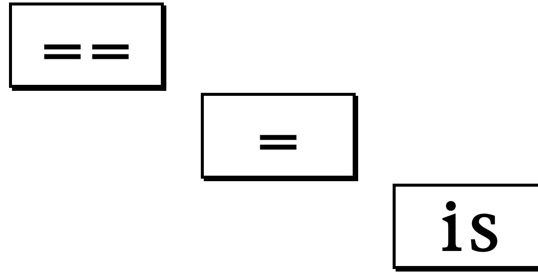
Arithmetic

```
:-  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
```



:- 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)

Prolog syntax delimited by period

write (X)
nl

Characters

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

Primitive but can be extended

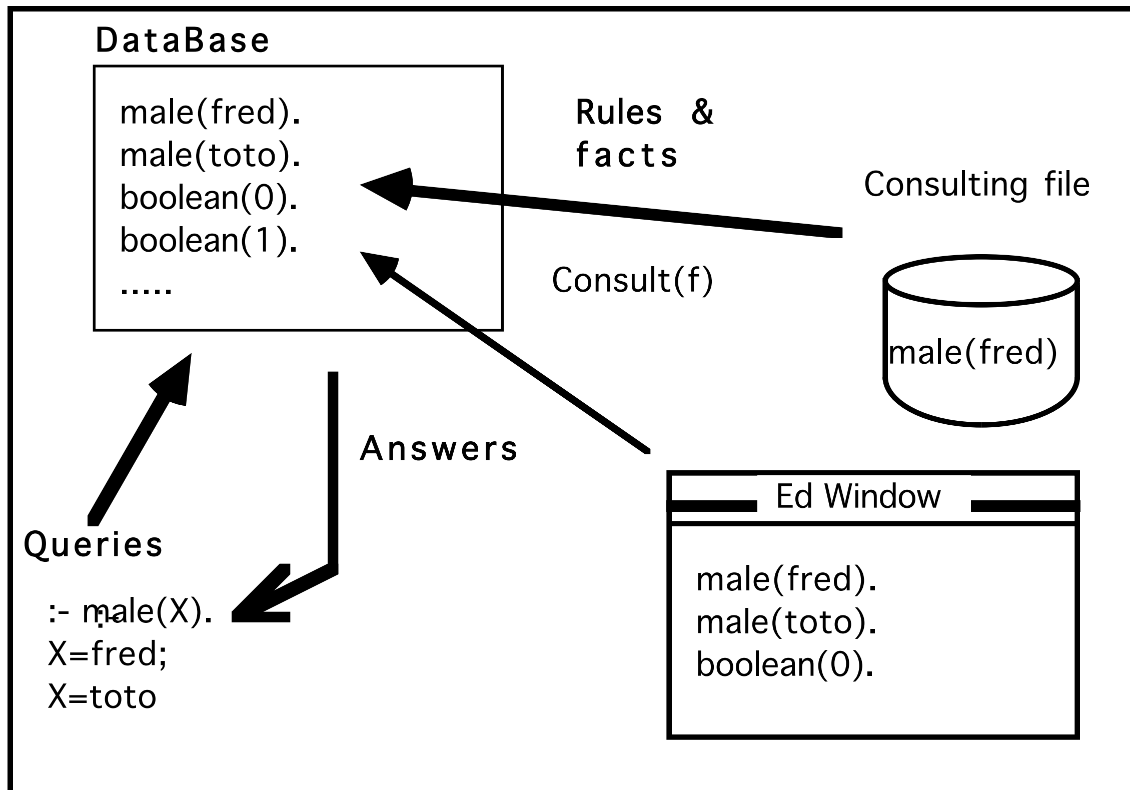
M-Prolog, Prolog II primitives

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

<u>Lists:</u>

- Dynamic data structures
- Trees
- Graphs

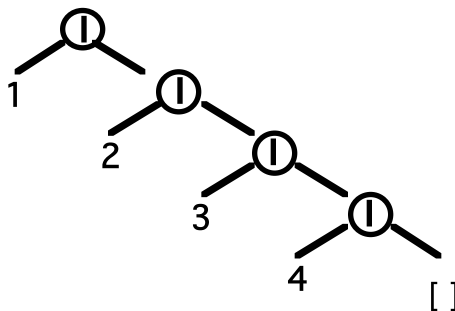
LISP: (1 2 3 4)
nil
(1 ((2) 3) 4)

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

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

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

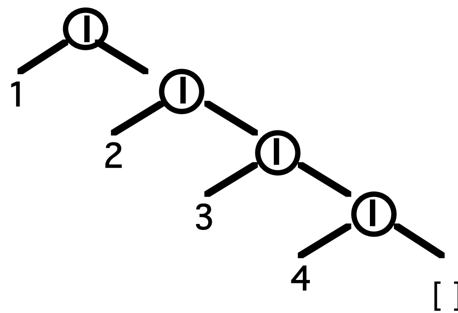
PROLOG:

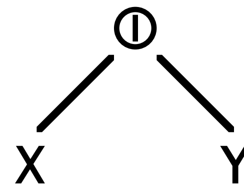


List Processing

- Accessing elements
- Building lists

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





=> 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

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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