Prolog

- proof process
  - generate subgoals
  - replace variables by values
    - unification: find suitable set of values so that goal can be matched to fact or head of rule
- ordering and its effect on backtracking:
  - subgoals that are hardest to satisfy should be placed as early as possible in the program
- recursion:
  - recursive rule
  - stopping condition

Prolog – Recursion

```
child(X, Y) :- mother(X, Y).
child(X, Y) :- father(X, Y).

descendant(X, Y) :- child(X, Y).
descendant(X, Y) :- child(X, Z),
                    descendant(Z, Y).
```

Prolog - Negation

- negation
  - closed-world assumption: all facts about the world are included in the model
    - negation of anything not derivable is considered true

```
?- not typhoid(bill)
```

The `not` goal succeeds in two situations:

1. When `bill` has definitely not got typhoid.
2. When it cannot prove `bill` has typhoid.

Prolog - Negation

```
female(anne)
male(X) :- not female(X).
```

```
?- male(anne)
```

`No`

because `anne` is definitely not male

```
?- male(andrea)
```

`Yes`

because the system cannot prove that `andrea` is female (in Italy `andrea` is masculine)

Data Objects

- atoms: numbers and character strings
- structured objects
  - functor: the name
  - components

```
student(fullname(Forename, Surname), Age)

attends(student(fullname(mary, smith), 20), stirling).
attends(student(fullname(joe, brown), 25), stirling).
maturestudent(Surname) :-
   attends(student(fullname(Forename,Surname), Age),
       University), Age > 23.

?- maturestudent(X).

X = brown
```

Data Objects

- lists: `.` and `[]`
  - head: the first element
  - tail: the rest of the list
  - short form for list with head `X`, tail `Y`: `[X|Y]`
  - lists are represented as binary trees
- selector relations: to access components of a structure
  - hide representation of structure

```
forename(student(fullname(Forename,Surname), Age), Forename).

forename(student(fullname(Forename,_),_), Forename).
```

Efficiency

- backtracking:
  - depth-first search
  - subgoal evaluation from left to right
  - ordering of subgoals is crucial
- cut: `!`
  - stops backtracking
  - useful for mutually exclusive clauses

```
R :- G1, G2, !, G3
R :- G4
```

Efficiency - Example

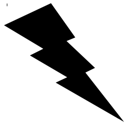
```
f(X, Y) :- X < 0, Y < 0.
f(X, Y) :- X = 0, Y = 0.
f(X, Y) :- X > 0, Y > 0.
```

```
?- f(-1, 1).

?- -1 < 0, 1 < 0.      ?- -1 = 0, 1 = 0.      ?- -1 > 0, 1 > 0.

?- 1 < 0.
```

Efficiency – Example (cont.)

```
f(X, Y) :- X < 0, !, Y < 0.
f(X, Y) :- X = 0, !, Y = 0.
f(X, Y) :- X > 0, Y > 0.
```

```
?- f(-1, 1).
        ↓
?- -1 < 0, !, 1 < 0.
        ↓
?- 1 < 0.
```



Efficiency

- cut: !
  - programs without cuts have same declarative and procedural meaning
    - slow but correct
  - programs with cuts may not have same declarative and procedural meaning
    - green cuts, red cuts

previous example

Efficiency – Red Cuts

```
male(george).
mother(jane, anne).
mother(jane, george).
father(john, anne).
father(john, george).

son(X, Y) :- father(Y, X), !, male(X)
son(X, Y) :- mother(Y, X), !, male(X)
```

`son(george, jane)` ⇒ `yes`

`son(anne, john)` ⇒ `no`

but `son(X, jane)` ⇒ `no` instead of `X = george`.

Prolog - Example

Symbolic differentiation:

```
4 * power(x, 3)          power(x, 3)

12 * power(x, 2)         3 * power(x, 2)
```

To differentiate an expression `Y` with respect to `X` giving the result `E`, the heads of the rules will have the form `derive(Y, X, E)`.

Prolog - Example

First attempt:

```
derive(A * F, X, A * C) :- integer(A), derive(F, X , C).
derive(power(X, N), X, N * power(X, N - 1)) :- integer(N).

?- derive(4 * power(x, 3), x, E).
      (A ← 4, F ← power(x, 3), X ← x, E ← A * C)
⇒ integer(4), derive(power(x, 3),x, C).
⇒ derive(power(x, 3), C).
      (X ← x, N ← 3, C ← N * power(X, N - 1))
⇒ integer(3).
```

result: `E = 4 * (3 * power(x, 3 - 1))`

Example (cont.)

```
derive(A * F, X, G * B) :-
   integer(A), derive(F, X , D * B), G is A * D.
derive(power(X, N), X, N * power(X, P)) :-
   integer(N), P is N - 1.

?- derive(4 * power(x, 3), x, E).
        (A ← 4, F ← power(x, 3), X ← x, E ← G * B)
⇒ integer(4), derive(power(x, 3), x, D * B), G is 4 * D.
⇒ derive(power(x, 3), x, D * B), G is 4 * D.
        (X ← x, N ← 3, D ← 3, B ← power(x, P))
⇒ integer(3), P is 3 - 1, G is 4 * 3.
⇒ P is 2, G is 12.
```

result: `E = 12 * power(x, 2)`

ELIZA

`ELIZA` simulates a therapist by generating suitable questions according to the input.

Weizenbaum, J., "ELIZA -- A computer program for the study of natural language communication between man and machine", Communications of the ACM 9(1):36-45, 1966.

Example:

```
   I am unhappy.
>> How long have you been unhappy?
   Six month. Can you help me?
>> What make you think I help you?
   You remind me of my father and brother.
>> Can you tell me more about father.
   I like teasing father.
>> Does anyone else in your family like teasing father.
   No, only me.
>> Please go on.
```

ELIZA (cont.)

We will implement the basic algorithm without considering I/O.

Sterling L., Shapiro E.,"Prolog – Fortgeschrittene Programmiertechniken", Addison-Wesley Publishing Company, 1986

`eliza` is a predicate on pairs of lists of atoms representing the input resp. the output.

```
eliza([bye], [goodbye,i,hope,i,have,helped,you]).
eliza(Input, Output) :-
   pattern(Stimulus, Answer),
   match(Stimulus, Table, Input),
   match(Answer, Table, Output), !
```

ELIZA (cont.)

```
pattern([i,am,1],[how,long,have,you,been,1,?]).
pattern([1,you,2,me],[what,makes,you,think,i,2,you,?]).
pattern([i,like,1],[does,anyone,else,in,your family,like,1,?]).
pattern([i,feel,1],[do,you,often,feel,this,way,?]).
pattern([1,X,2],[can,you,tell,me,more,about,X,?)
   :- important(X).
pattern([1],[please,go,on]).

important(father).
important(mother).
important(son).
important(daughter).
important(sister).
important(brother).
```

ELIZA (cont.)

`search` returns a value which is stored for a key in a dictionary. The dictionary is represented by a list of pairs `(Key, Value)`.

```
search(Key, [(Key, Value)|Dictionary], Value).
search(Key1, [(Key2, Value1)|Dictionary], Value2) :-
       search(Key1, Dictionary, Value2).
```

ELIZA (cont.)

```
match([N|Pattern], Table, Target) :-
   integer(N),
   search(N, Table, LeftTarget),
   append(LeftTarget, RightTarget, Target),
   match(Pattern, Table, RightTarget).
match([Word|Pattern], Table, [Word|Target]) :-
   atom(Word),
   match(Pattern, Table, Target).
match([], Table, []).
```