Prolog

- Logic programming (declarative)
  - Goals and subgoals
- Prolog Syntax
- Database example
  - rule order, subgoal order, argument invertibility, backtracking model of execution, negation by failure, variables
- Data structures (lists, trees)
  - Recursive Functions: append, member
  - Lazy evaluation, terms as trees, Prolog search trees
- Goal-oriented semantics

Intro to Logic Programming

- Specifies relations between objects

  larger (2,1), father (tom, jane)
- Separates control in PL from description of desired outcome

  father(X, jane) :- male(X), parent(X, jane).
- Computation engine: theorem proving and recursion
  - Higher-level PL than imperative languages
  - More accessible to non-technical people

Horn Clauses

- Conjunct of 0 or more conditions which are atomic formulae in predicate logic (constants, predicates, functions)

  $h_1 \wedge h_2 \wedge \ldots \wedge h_n \rightarrow c$
- Means c if h_1 , h_2 ,…, h_n are all true
- Can have variables in the h_i's or c

  $c(x_1, x_2, \ldots, x_m)$ if $h(x_1, x_2, \ldots, x_m, y_1, \ldots, y_k)$

  means for all objects x_1 , x_2 , … , x_m , c holds if there are objects y_1 ,…, y_k such that h holds.

  father(X, jane) :- male(X), parents(X, Y, jane)

Logic Programming

- Goal-oriented semantics
  - goal is true for those values of variables which make each of the subgoals true
    - *father(X, jane)* will be true if *male(X)* and *parents(X,Y,jane)* are true with specific values for *X* and *Y*
  - recursively apply this reasoning until reach rules that are facts.
  - called *backwards chaining*

Logic Programming

- Nondeterminism
  - Choice of rule to expand subgoal by
  - Choice of subgoal to explore first

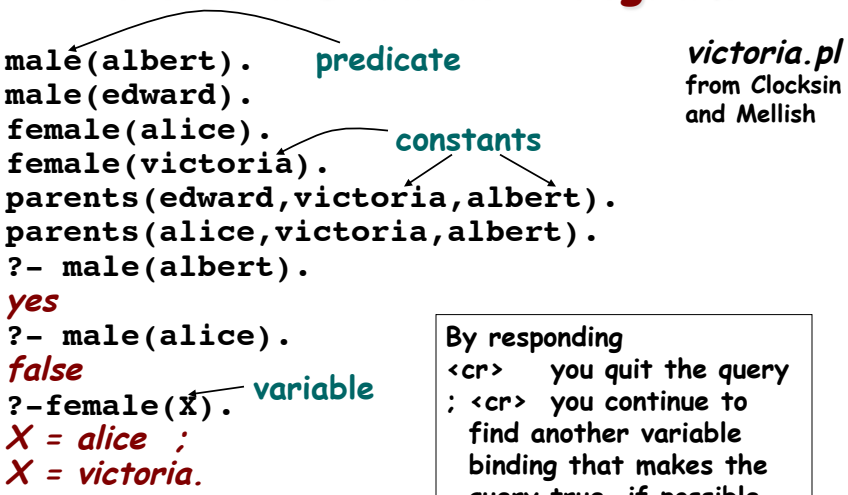
father(X,jane):- male(X), parents(X, Y, jane).
father (X,jane):- father (X,Y), brother(Y, jane).

which rule to use first? which subgoal to explore first?

- Prolog tries rules in sequential order and proves subgoals from left to right. - Deterministic!

father(X, jane) :- male(X), parent(X, jane).

Victoria Database Program



victoria.pl
from Clocksin and Mellish

By responding
<cr> you quit the query
; <cr> you continue to find another variable binding that makes the query true, if possible.

Victoria Example

- Problem: facts alone do not make interesting programs possible. Need variables and deductive rules.

```
?-female(X).          a query or proposed fact
X = alice    ;        ; asks for more answers
X = victoria.  if user types <cr> then no
               more answers given when no more
               satisfying answers are left.
```

Variable X has been unified to all possible values that make `female(X)` true.

- Performed by pattern match search

Prolog Syntax in EBNF

15 jane X

<term> → <integer> | <atom> | <variable> |
<functor> (<term> {, <term>})

head :- body

<rule> → <predicate> (<term> {,<term>}):-
<term> {, <term>} . | <fact>

<fact> → <functor> (<term>) {, <term>}).

<query> → ?- <functor>(<term>{,<term>}).

a proposed fact that must be proven

Prolog Syntax, cont.

- Prolog program consists of facts, rules, and queries
- A query is a proposed fact, needing to be proven
  - If query has no variables and is provable, answer is *yes*
  - If query has variables, the proof process causes some variables to be bound to values which are reported (called a *substitution*)
- Variable names are capitalized, predicate names and constants are lower case.
- Names (e.g., predicates, functors with terms, clauses) come from first order logic.

Victoria Example, cont.

```
sister_of(X,Y) :- female(X),parents(X,M,F),
  parents(Y,M,F).
?- sister_of(alice, Y).
```

Y = edward

```
?- sister_of(X,Y).
```

X = alice
Y = edward ;
X =Y, Y = alice ;
false

```
3. female(alice).
4. female(victoria).
5. parents(edward,victoria,albert).
6. parents(alice,victoria,albert).
```

first answer from 3.+6.+5.
second answer from 3.+6.+6.

Subgoal order, argument invertibility, backtracking, rule order

Victoria Example, cont.

```
sis(X,Y) :- female(X), parents(X,M,F),
  parents(Y,M,F),\+(X==Y).
```

```
?- sis(X,Y).
X = alice
Y = edward  ;
false
```

= means *unifies with*

== means *same in value*

\+ (P) succeeds when P fails; called negation by failure

Negation by Failure

```
not(X) :- X, !, fail.
not( _ ) .
```

if X succeeds in first rule, then the goal fails because of the last term.

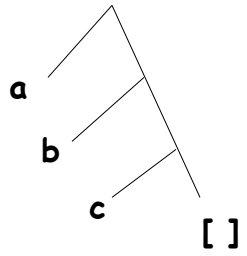
if we type ";" the cut (!) will prevent us from backtracking over it or trying the second rule so there is no way to undue the fail.

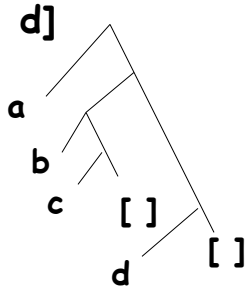
if X fails in the first rule, then the goal fails because subgoal X fails. the system tries the second rule which succeeds, since "_" (don't care variable) unifies with anything.

Lists

list	head	tail
[a,b,c]	a	[b,c]
[a, [b, c], d]	a	[[b,c], d]
[X | Y]	X	Y

a list consists of a sequence of terms





Unifying Lists

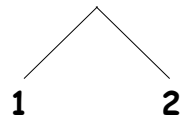
[X,Y,Z] = [john, likes, fish]

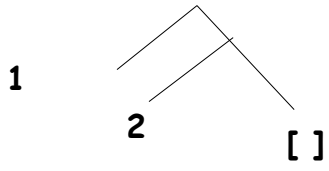
X = john, Y = likes, Z = fish

[cat] = [X | Y]

X = cat, Y = [ ]

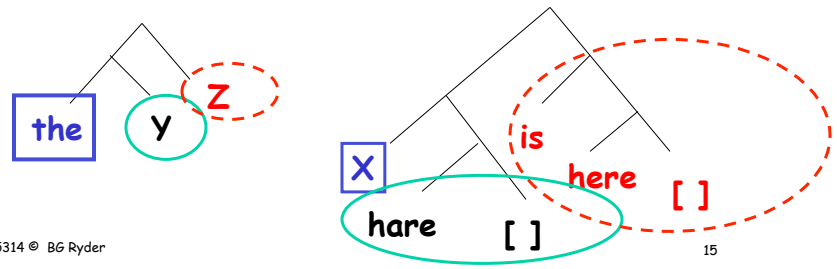
[1 | 2] versus [1, 2]





Lists

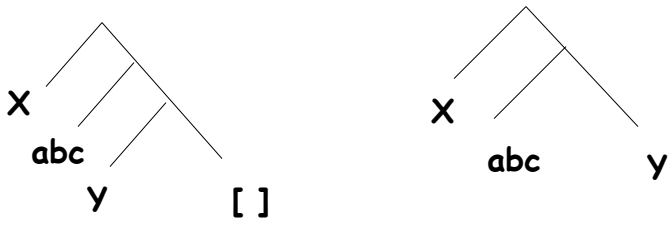
- Sequence of elements separated by commas, or
- [first element | rest_of_list]
  - Like Scheme notation [car(list) | cdr(list)]
- [[the | Y] | Z] = [[X, hare] | [is, here]]



Lists

[X, abc, Y] =? [X, abc | Y]

thre is no value binding for Y, to make these two trees isomorphic.



Be careful of unifications that mix list syntax modes.

Lists

don' t care variable unifies with anything

[a,b | Z] =? [X | Y]

X = a, Y = [b | Z], Z = _

look at the trees to see why this works!

[a, b, c] = [X | Y]

X = a, Y = [b,c].

Member_of Function

```
member(A, [A | B] ).
member(A, [B | C]) :- member (A, C).
```

goal-oriented semantics: can get value assignment for goal member(A,[B|C]) by showing truth of subgoal member(A,C) and retaining value bindings of the variables

Example

Invertibility of Prolog arguments

```
?- member(a,[a,b]).
   yes
?- member(a,[b,c]).
   false
?- member(X,[a,b,c]).
   X = a  ;
   X = b ;
   X = c ;
   false
```

1. member(A, [A | B]).
2. member(A, [B | C]) :- member (A, C).

Try this last query with trace.

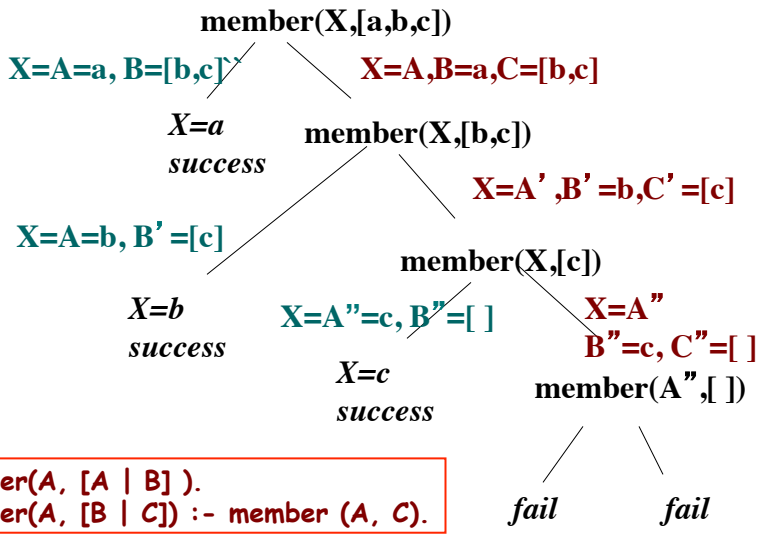
Example

```
?- member(a,[b, c, X]).
   X= a  ;
   false
?- member(X,Y).
   X = _123
   Y = [ X | _124] ) ;
   X = _123
   Y = [_125, X | _126]  ;
   X = _123
   Y =  [ _127, _128, X |_129]
```

1. member(A, [A | B]).
2. member(A, [B | C]) :- member (A, C).

Lazy evaluation of *a priori* unbounded list structure. Unbound X variable is first element, then second element, then third element, in a sequence of generated lists of increasing length.

Prolog Search Tree



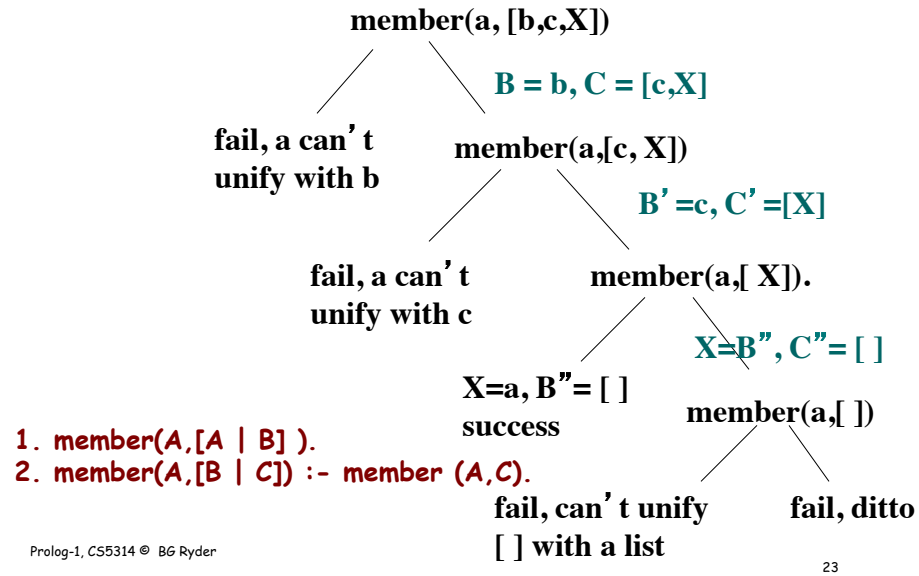

```
1. member(A, [A | B] ).
2. member(A, [B | C]) :- member (A, C).
```



```
1. member(A, [A | B] ).
2. member(A, [B | C]) :- member (A, C).
```


```
?- member(X, [a,b,c]).
match rule 1.  member(A, [A | B] ) so X = A = a, B = [b,c]
   X = a   ;
match rule 2.  member(A, [B | C]) so X = A, B = a, C = [b,c]
then evaluate subgoal member(X, [b,c])
   match rule 1. member(A' ,[A' | B' ]) so  X = b, B '= [c]
        X = b  ;
   match rule 2. member(A' ,[B' | C' ]) so X = A' , B '= b, C' = [c]
   then evaluate subgoal member(X, [c])
        match rule 1. member(A",[A" | B"]) so X=A"= c, B"=[ ]
              X = c  ;
        match rule 2. member(A",[B" | C"]) so X=A", B"=c,C"=[ ],
        but member(X, [ ]) is unsatisfiable,  no
```

Another Search Tree



1. member(A,[A | B]).
2. member(A,[B | C]) :- member (A,C).

Prolog Search Trees

- A formalism to consider all possible computation paths
  - Leaves are success nodes or failures where computation cannot proceed
  - To model Prolog, leftmost subgoal is tried first
  - Label edges with variable bindings that occur by *unification*
  - There can be infinite branches in the tree, representing non-terminating computations (performed lazily (i.e., generate as needed) by Prolog);

Another Member_of Function

Equivalent set of rules:

```
mem(A,[A|_] ).
mem(A,[_| C]) :- mem(A,C).
```

Can examine search tree and see the variables which have been excised were auxiliary variables in the clauses.

Append Function

```
append ([ ],A,A).
append([A|B],C,[A|D]):- append(B,C,D).
```

- Build a list

```
?- append([a],[b],Y).
```

Y = [a,b]

- Break a list into constituent parts

```
?- append(X,[b],[a,b]).
```

X = [a]

```
?- append([a],Y,[a,b]).
```

Y = [b]

More Append

```
?- append(X, Y, [a,b]).
X = [ ]
Y = [ a, b ]      ;
X = [a]
Y = [b]    ;
X = [a,b]
Y = [ ]    ;
false
```

```
append ([ ],A,A).
append([A|B],C,[A|D]):- append(B,C,D).
```


Still More Append

- Generating an unbounded number of lists

```
?- append(X, [b], Y).
X = [ ]
Y = [b]   ;
X = [ _169]
Y =  [ _169, b]   ;
X = [ _169, _170 ]
Y = [ _169,  _170, b]  ;
etc.
```

```
append ([ ],A,A).
append([A|B],C,[A|D]):- append(B,C,D).
```

Common Beginner's Errors

- Compile-time
  - Forget ending "."
  - Misspelled functors
  - Need to override precedences with (..)
- Runtime
  - Infinite loops - check your recursion
  - Variables instantiated with unexpected values
  - Circular definitions
  - Giving wrong numbers of arguments to a clause