CMSC 330: Organization of Programming Languages

Logic Programming with Prolog Lists

Review: Execution = Search

- Prolog execution: Goal-directed search
  - Query = predicate you wish to prove is true
- Key feature: unification
  - Two terms unify if they are identical, or they can be made identical by substituting variables
    - is_bigger(X, gnat) = is_bigger(horse, gnat) when X=horse
    - execution goal is often to discover such X
- Attempt to unify goal with head of a rule
  - If succeeds, clauses in body become subgoals
  - Continue until all subgoals satisfied
    - If search fails, backtrack and try untried subgoals

Review: Equality

- Not all forms of equality are the same!
  - p = q *iff* p unifies with q
  - p is q *iff* p unifies with q’ where q’ is q evaluated
    - Meaning that q’ is treated as an arithmetic expression, and run as such
  - p =:= iff p’ unifies with q’ where q’ is q evaluated and p’ is p evaluated
  - p == q iff p and q are identical
    - No substitutions or evaluations permitted

Warmup: What is the query result?

```
john(C, E, N, A) :-
  C = N,
  E = A,
  C = 2 + 3.
?- john(5, 1, 5, 1).
```

A. true
B. false

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Lists In Prolog

- [a, b, 1, ‘hi’, [X, 2]]
- But really represented as compound terms
  - [ ] is an atom
  - [a, b, c] is represented as .(a, .(b, .(c, [])))
- Matching over lists

```
?- [X, 1, Z] = [a, _, 17]
X = a,
Z = 17.
```

List Deconstruction

- Syntactically similar to Ocaml: [H|T] like h::t

```
?- [Head | Tail] = [a,b,c].
Head = a,
Tail = [b, c].
```

```
?- [1,2,3,4] = [ _, X | _].
X = 2
```

- This is sufficient for defining complex predicates
- Let's define concat(L1, L2, C)

```
?- concat([a,b,c], [d,e,f], X).
X = [a,b,c,d,e,f].
```

Example: Concatenating Lists

- To program this, we define the "rules" of concatenation
  - If L1 is empty, then C = L2

```
concat( [ ], L2, L2 ).
```

  - Prepending a new element to L1 prepends it to C, so long as C is the concatenation of L1 with some L2

```
concat( [E | L1], L2, [E | C] ) :-
   concat(L1, L2, C).
```

- … and we're done

Why Is The Return Value An Argument?

- Now we can ask what inputs lead to an output

```
?- concat(X, Y, [a,b,c]).
X = [ ],
Y = [a, b, c] ;
X = [a],
Y = [b, c] ;
X = [a, b],
Y = [c] ;
X = [a, b, c],
Y = [ ] ;
```

User types ; to request additional answers

Quiz 1: T/F: This is a Valid Prolog List

[3, 4, 'papaya', blueberry]

A. True
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Quiz 2: What does this query return?

?- [a|T] = [a,b,c,[d,a],[1,2],list].

A. T = [b, c, [d, a], [1, 2], list].
B. false
C. T = [d, a]
D. T = list

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Quiz 3: What does mystery(A,L) do?

```
mystery(X, [H|T]) :- X = H.
mystery(X, [H|T]) :- mystery(X,T).
```

A. Evaluates to false if A is contained in list L
B. Evaluates to true if A is contained in list L
C. Assigns the last element in L to A
D. Assigns the first element in L to A

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Quiz 4: What's result of mystery(A,B) ?

```
mystery(L1,L2) :-
    L1 = [H|T1],
    L2 = [H,H|T2].
```

A. true if A and B have equal lengths
B. true if the first element in A is equal to the first and the last element in B.
C. true if the first element in A is equal to the first and the second element in B.
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Built-in List Predicates

- length(List,Length)

  ?- length([a, b, [1,2,3]], Length).
  Length = 3.

- member(Elem,List)

  ?- member(duey, [huey, duey, luey]).
  true.

  ?- member(X, [huey, duey, luey]).
  X = huey; X = duey; X = luey.

- append(List1,List2,Result)

  ?- append([duey], [huey, duey, luey], X).
  X = [duey, huey, duey, luey].

Built-in Predicates

- sort(List,SortedList)

  ?- sort([2,1,3], R).
  R= [1,2,3].

- findall(Elem,Predicate,ResultList)

  ?- findall(E,member(E,[huey, duey, luey]),R).
  R=[huey,duey,luey].

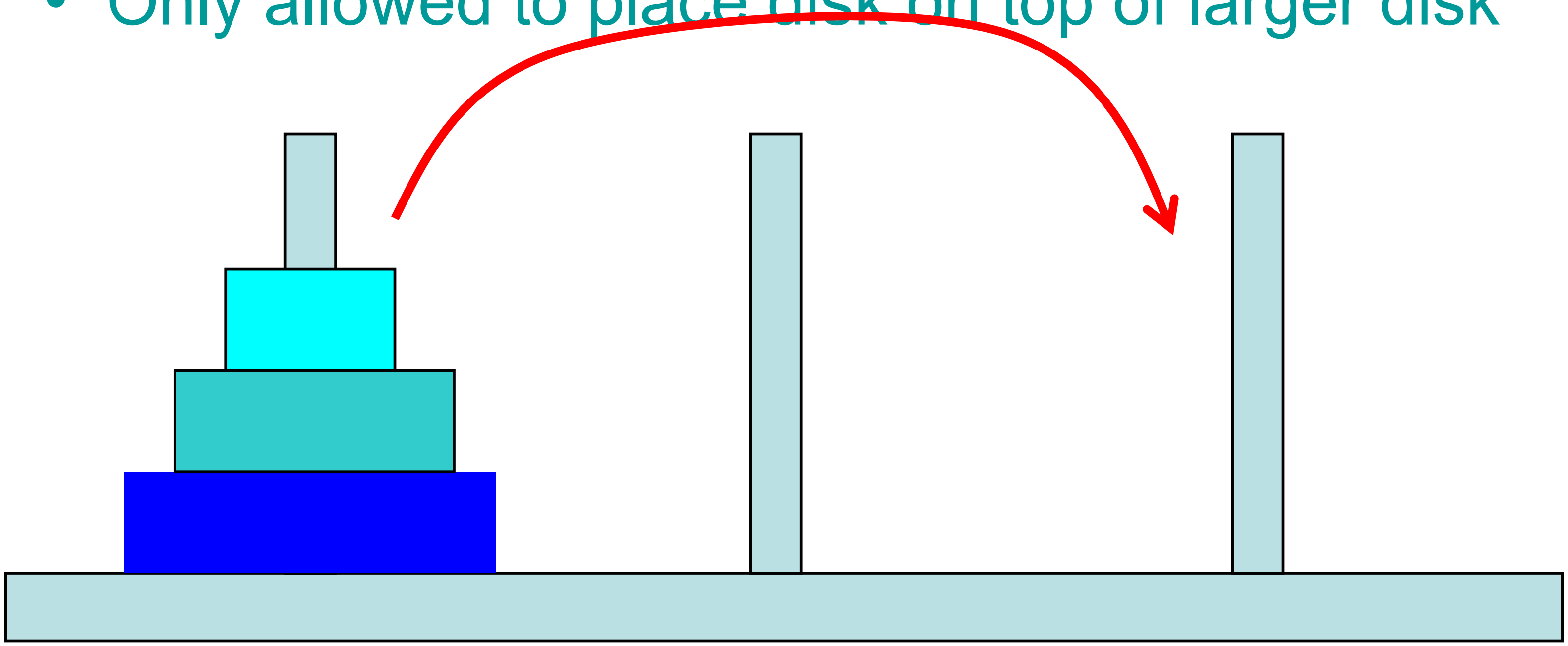
- setof(Elem,Predicate,ResultSortedList)

  ?- setof(E,member(E,[huey, duey, luey]),R).
  R=[duey,huey,luey].

- See documentation for more
  - http://www.swi-prolog.org/pldoc/man?section=builtin

Example – Towers of Hanoi

- Problem
  - Move stack of disks between pegs
  - Can only move top disk in stack
  - Only allowed to place disk on top of larger disk



Example – Towers of Hanoi

- To move a stack of n disks from peg X to Y
  - Base case
    - If $n = 1$, move disk from X to Y
  - Recursive step
    1. Move top n-1 disks from X to 3rd peg (Z)
    2. Move bottom disk from X to Y
    3. Move top n-1 disks from 3rd peg (Z) to Y

Iterative algorithm would take much longer to describe!

Towers of Hanoi

- Code

```
move(1,X,Y,_) :-
    write('Move top disk from '), write(X),
    write(' to '), write(Y), nl.
move(N,X,Y,Z) :-
    N>1,
    M is N-1,
    move(M,X,Z,Y),
    move(1,X,Y,_),
    move(M,Z,Y,X).
```

Prolog Terminology

- A query, goal, or term where variables do not occur is called ground; else it's nonground
  - foo(a,b) is ground; bar(X) is nonground
- A substitution θ is a partial map from variables to terms where domain(θ) $\cap$ range(θ) = $\varnothing$
  - Variables are terms, so a substitution can map variables to other variables, but not to themselves
- A is an instance of B if there is a substitution such that A = Bθ ← `The substitution θ applied to B`
- C is a common instance of A and B if it is an instance of A and an instance of B

Prolog's Algorithm Solve()

Starts as empty

Solve(goal G, program P, substitution θ) =

- Suppose G is $A_1,\ldots,A_n$. Choose goal A_1.
- For each clause A :- $B_1,B_2,\ldots,B_k$ in P,
  - if θ_1 is the mgu of A and $A_1\theta$ then
    - If Solve($\{B_1,\ldots,B_k,A_2,\ldots,A_n\}$, P, $\theta\cdot\theta_1$) = some θ' then **return** θ'
    - (else it has failed, so we continue the for loop)
  - (else unification has failed, so try another rule)
- If loop exits return fail
- Output: θ s.t. $G\theta$ can be deduced from P, or fail

Chooses goals in order

Most General Unifier

Implements backtracking