CS F214 - Logic in CS
Prolog – Lecture 2

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Jagat Sesh Challa

Today’s Lecture

- Recursion
- Lists
- Arithmetic

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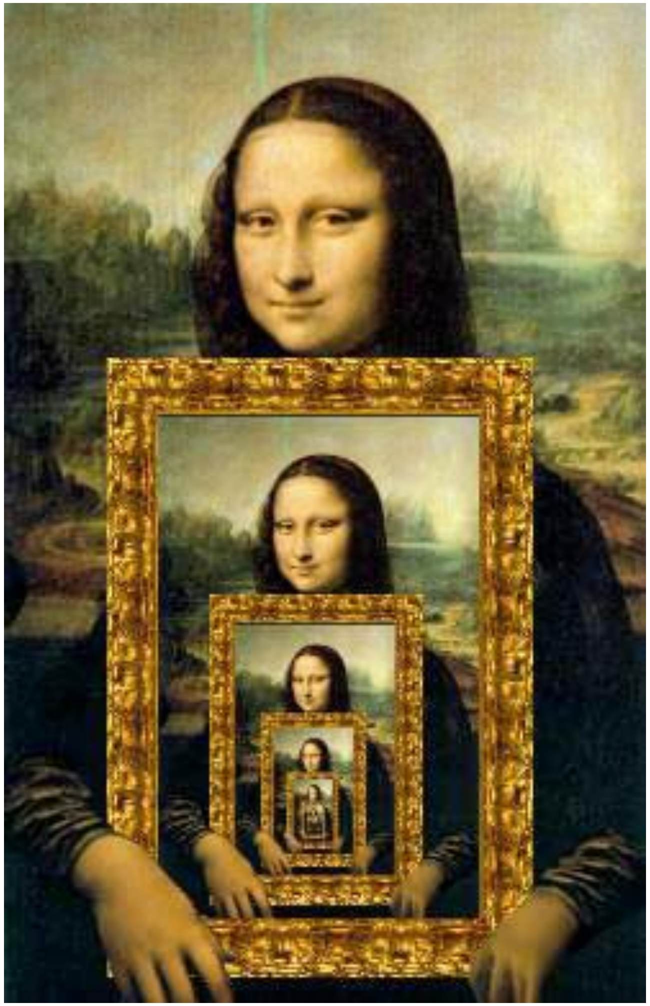
Recursion

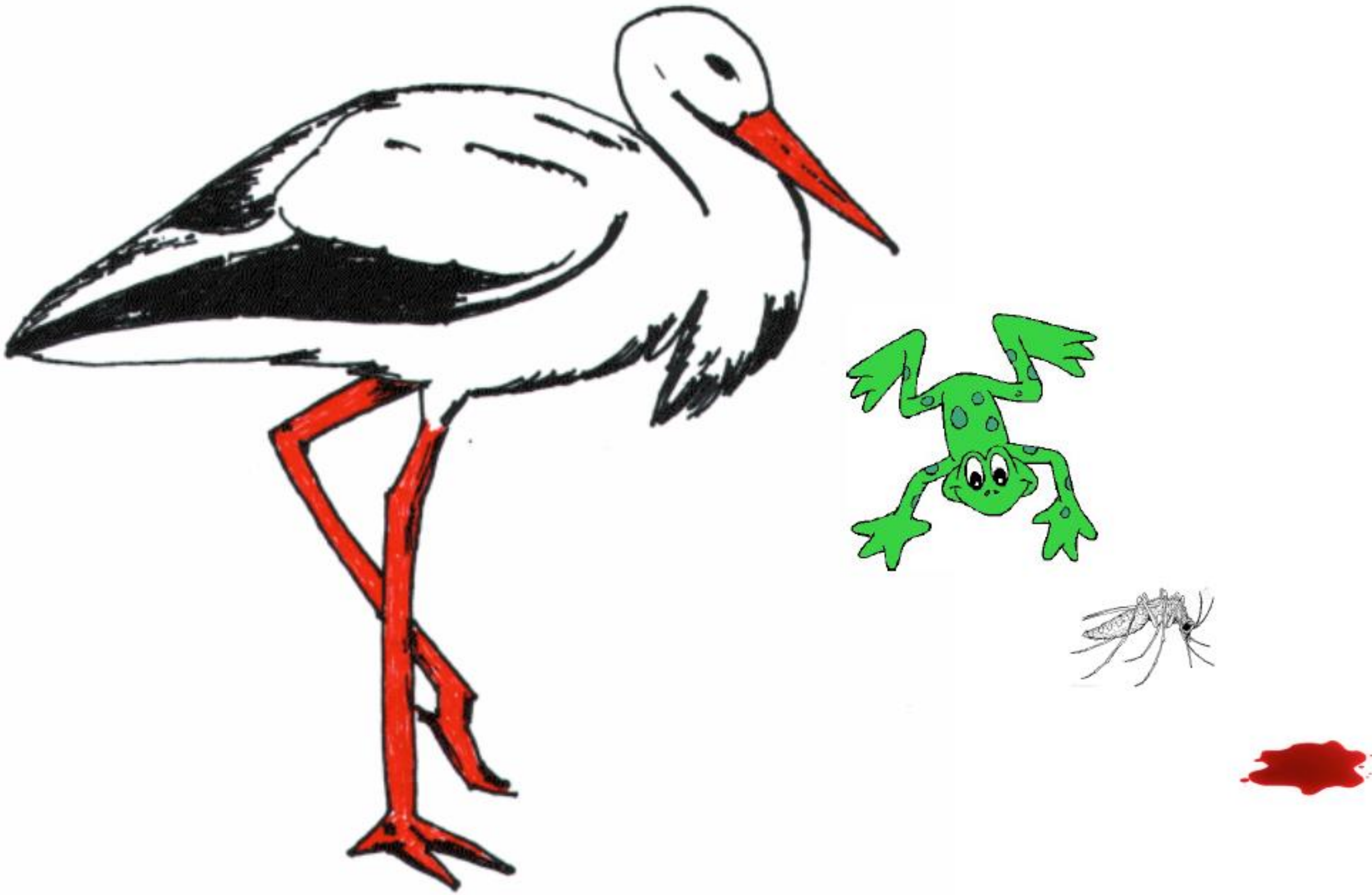
Recursion



Recursive definitions

- Prolog predicates can be defined recursively
- A predicate is recursively defined if one or more rules in its definition refers to itself

Example 1: Eating

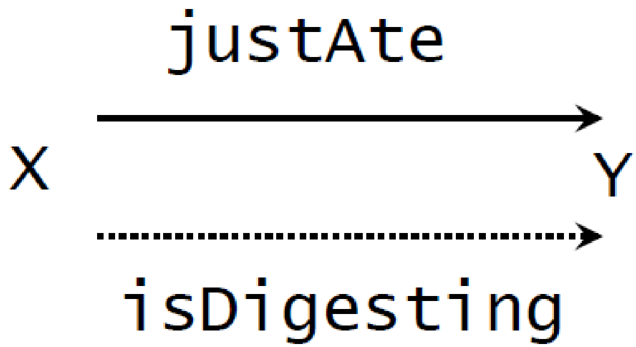


Example 1: Eating

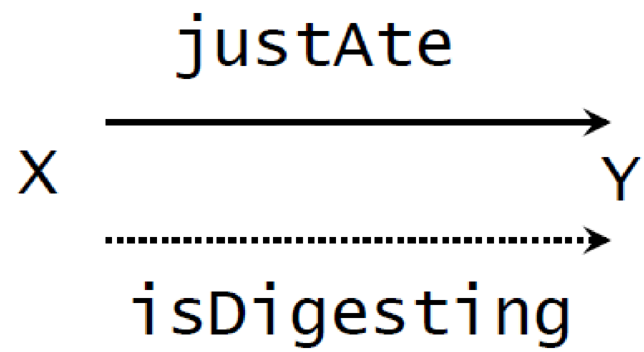
```
isDigesting(X,Y):- justAte(X,Y).
isDigesting(X,Y):- justAte(X,Z), isDigesting(Z,Y).

justAte(mosquito,blood(john)).
justAte(frog,mosquito).
justAte(stork,frog).
```

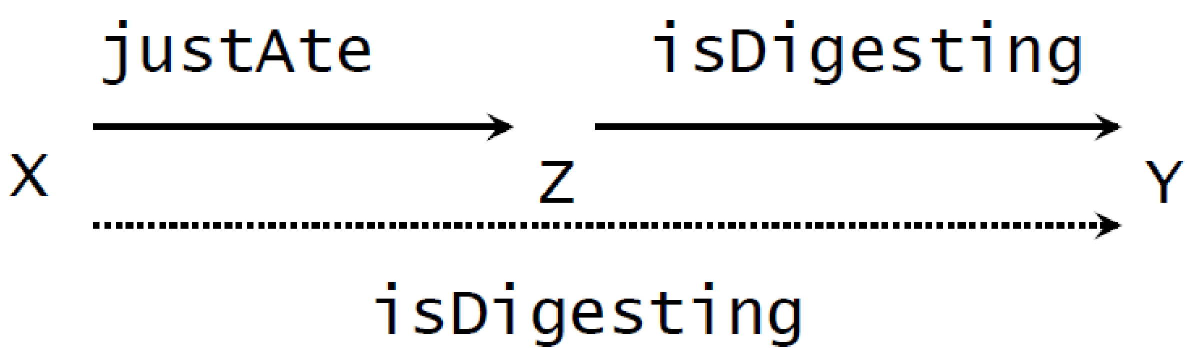
```
?-
```

Picture of the Situation



Picture of the Situation





Example 1: Eating

```
isDigesting(X,Y):- justAte(X,Y).
isDigesting(X,Y):- justAte(X,Z), isDigesting(Z,Y).

justAte(mosquito,blood(john)).
justAte(frog,mosquito).
justAte(stork,frog).
```

```
?- isDigesting(stork,mosquito).
```

Example 1: Eating

```
isDigesting(X,Y):- justAte(X,Y).
isDigesting(X,Y):- justAte(X,Z), isDigesting(Z,Y).

justAte(mosquito,blood(john)).
justAte(frog,mosquito).
justAte(stork,frog).
```

```
?- isDigesting(stork,mosquito).
yes
?-
```

Example 2 - descendent

```
child(anna,bridget).
child(bridget,caroline).
child(caroline,donna).
child(donna,emily).


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

Example 2 - descendent

```
child(anna,bridget).
child(bridget,caroline).
child(caroline,donna).
child(donna,emily).



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

```
?- descend(anna,donna).
no
?-
```

Example 2 - descendent

```
child(anna,bridget).
child(bridget,caroline).
child(caroline,donna).
child(donna,emily).


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

```
?-
```

Example 3 - Successor

Suppose we use the following way to write numerals:

1. **0** is a numeral.
2. If **X** is a numeral, then so is **succ(X)**.

Example 3 - Successor

```
numeral(0).
numeral(succ(X)):- numeral(X).
```

Example 3 - Successor

```
numeral(0).
numeral(succ(X)):- numeral(X).
```

```
?- numeral(succ(succ(succ(0)))).
yes
?-
```

Example 3 - Successor

```
numeral(0).
numeral(succ(X)):- numeral(X).
```

```
?- numeral(X).
```

Example 3 - Successor

```
numeral(0).
numeral(succ(X)):- numeral(X).
```

```
?- numeral(X).
X=0;
X=succ(0);
X=succ(succ(0));
X=succ(succ(succ(0)));
X=succ(succ(succ(succ(0))))
```

Example 4 - Addition

```
?- add(succ(succ(0)),succ(succ(succ(0))), Result).
Result=succ(succ(succ(succ(succ(0)))))
yes
```

Example 4 - Addition

```
add(0,X,X).                    %%% base clause
```

```
?- add(succ(succ(0)),succ(succ(succ(0))), Result).
Result=succ(succ(succ(succ(succ(0)))))
yes
```

Example 4 - Addition

```
add(0,X,X).                     %%% base clause

add(succ(X),Y,succ(Z)):-        %%% recursive clause
    add(X,Y,Z).
```

```
?- add(succ(succ(0)),succ(succ(succ(0))), Result).
Result=succ(succ(succ(succ(succ(0)))))
yes
```

Prolog and Logic

- Prolog was the first reasonable attempt to create a logic programming language
  - Programmer gives a declarative specification of the problem, using the language of logic
  - The programmer should not have to tell the computer what to do
  - To get information, the programmer simply asks a query

Prolog and Logic

- Prolog does some important steps in this direction
- Nevertheless, Prolog is **not** a full logic programming language!
- Prolog has a specific way of answering queries:
  - Search knowledge base from top to bottom
  - Processes clauses from left to right
  - Backtracking to recover from bad choices

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Lists

Lists

- A list is a finite sequence of elements
- Examples of lists in Prolog:

[mia, vincent, jules, yolanda]

[mia, robber(honeybunny), X, 2, mia]

[ ]

[mia, [vincent, jules], [butch, friend(butch)]]

[[ ], dead(z), [2, [b,c]], [ ], Z, [2, [b,c]]]

Important things about lists

- List elements are enclosed in square brackets
- The length of a list is the number of elements it has
- All sorts of Prolog terms can be elements of a list
- There is a special list:

    the empty list [ ]

Head and Tail

- A non-empty list can be thought of as consisting of two parts
  - The head
  - The tail
- The head is the first item in the list
- The tail is everything else
  - The tail is the list that remains when we take the first element away
  - The tail of a list is always a list

Head and Tail example 1

[mia, vincent, jules, yolanda]

Head: mia

Tail: [vincent, jules, yolanda]

Head and Tail example 2

[[ ], dead(z), [2, [b,c]], [ ], Z, [2, [b,c]]]

Head: [ ]

Tail: [dead(z), [2, [b,c]], [ ], Z, [2, [b,c]]]

Head and Tail example 3

[dead(z)]

Head: dead(z)

Tail: [ ]

Head and tail of empty list

- The empty list has neither a head nor a tail
- For Prolog, [ ] is a special simple list without any internal structure
- The empty list plays an important role in recursive predicates for list processing in Prolog

The built-in operator |

- Prolog has a special built-in operator | which can be used to decompose a list into its head and tail
- The | operator is a key tool for writing Prolog list manipulation predicates

The built-in operator |

```
?- [Head|Tail] = [mia, vincent, jules, yolanda].

Head = mia
Tail = [vincent,jules,yolanda]
yes


?-
```

The built-in operator |

```
?- [X|Y] = [mia, vincent, jules, yolanda].

X = mia
Y = [vincent,jules,yolanda]
yes

?-
```

The built-in operator |

```
?- [X|Y] = [ ].

no

?-
```

The built-in operator |

```
?- [X,Y|Tail] = [[ ], dead(z), [2, [b,c]], [], Z, [2, [b,c]]] .

X = [ ]
Y = dead(z)
Z = _4543
Tail = [[2, [b,c]], [ ], Z, [2, [b,c]]]
yes

?-
```

Anonymous variable

- Suppose we are interested in the second and fourth element of a list

```
?- [X1,X2,X3,X4|Tail] = [mia, vincent, marsellus, jody, yolanda].
X1 = mia
X2 = vincent
X3 = marsellus
X4 = jody
Tail = [yolanda]
yes

?-
```

Anonymous variables

- There is a simpler way of obtaining only the information we want:

```
?- [ _,X2, _,X4|_ ] = [mia, vincent, marsellus, jody, yolanda].
X2 = vincent
X4 = jody
yes

?-
```

- The underscore is the anonymous variable

The anonymous variable

- Is used when you need to use a variable, but you are not interested in what Prolog instantiates it to
- Each occurrence of the anonymous variable is independent, i.e. can be bound to something different

Member

- One of the most basic things we would like to know is whether something is an element of a list or not
- So let's write a predicate that when given a term X and a list L, tells us whether or not X belongs to L
- This predicate is usually called

member/2

member/2

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

```
?- member(yolanda,[yolanda,trudy,vincent,jules]).
yes
?-
```

member/2

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

```
?- member(vincent,[yolanda,trudy,vincent,jules]).
yes
?-
```

member/2

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

```
?- member(X,[yolanda,trudy,vincent,jules]).
```

member/2

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

```
?- member(X,[yolanda,trudy,vincent,jules]).
X = yolanda;
X = trudy;
X = vincent;
X = jules;
no
```

Exercise

The predicate a2b/2 takes two lists as arguments and succeeds

- if the first argument is a list of a's, and
- the second argument is a list of b's of exactly the same length

```
?- a2b([a,a,a,a],[b,b,b,b]).
yes
?- a2b([a,a,a,a],[b,b,b]).
no
?- a2b([a,c,a,a],[b,b,b,t]).
no
```

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Arithmetic

Arithmetic in Prolog

- Prolog provides a number of basic arithmetic tools
- Integer and real numbers

Arithmetic	Prolog
2 + 3 = 5	?- 5 is 2+3.
3 x 4 = 12	?- 12 is 3*4.
5 – 3 = 2	?- 2 is 5-3.
3 – 5 = -2	?- -2 is 3-5.
4 : 2 = 2	?- 2 is 4/2.
1 is the remainder when 7 is divided by 2	?- 1 is mod(7,2).

Example Queries

```
?- 10 is 5+5.
yes

?- 4 is 2+3.
no

?- X is 3 * 4.
X=12
yes

?- R is mod(7,2).
R=1
yes
```

Defining Predicates with Arithmetic

```
addThreeAndDouble(X, Y):-
    Y is (X+3) * 2.
```

```
?- addThreeAndDouble(1,X).
X=8
yes

?- addThreeAndDouble(2,X).
X=10
yes
```

Defining Predicates with Arithmetic

```
addThreeAndDouble(X, Y):-
    Y is (X+3) * 2.
```

A closer look

- It is important to know that +, -, / and * do not carry out any arithmetic
- Expressions such as 3+2, 4-7, 5/5 are ordinary Prolog terms
  - Functor: +, -, /, *
  - Arity: 2
  - Arguments: integers

A closer look

```
?- X = 3 + 2.
X = 3+2
yes

?- 3 + 2 = X.
X = 3+2
yes

?-
```

The is/2 predicate

- To force Prolog to actually evaluate arithmetic expressions, we have to use

  is

  just as we did in the other examples
- This is an instruction for Prolog to carry out calculations
- Because this is not an ordinary Prolog predicate, there are some restrictions

The is/2 predicate

```
?- X is 3 + 2.
X = 5
yes

?- 3 + 2 is X.
ERROR: is/2: Arguments are not sufficiently instantiated

?- Result is 2+2+2+2+2.
Result = 10
yes

?-
```

Restrictions on use of is/2

- We are free to use variables on the right hand side of the **is** predicate
- But when Prolog actually carries out the evaluation, the variables must be instantiated with a variable-free Prolog term
- This Prolog term must be an arithmetic expression

Notation

- Two final remarks on arithmetic expressions
  - 3+2, 4/2, 4-5 are just ordinary Prolog terms in a user-friendly notation:

    3+2 is really **+(3,2)** and so on.
  - Also the **is** predicate is a two-place Prolog predicate

```
?- is(X,+(3,2)).
X = 5
yes
```

Next…

- Arithmetic and Lists
- Append/2
- Reverse/2 & Reverse/3