Logic Programming

Using Data Structures
Part 1

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Contents

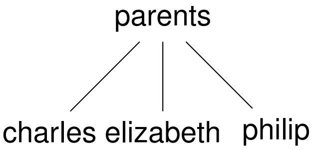
Representing Structures as Trees

Structures can be represented as trees:

- Each functor — a node.
- Each component — a branch.

Example

parents(charles,elizabeth,philip).

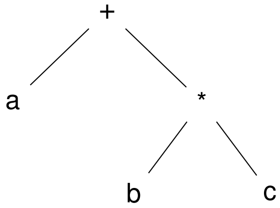


Representing Structures as Trees

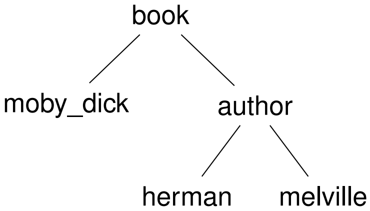
Branch may point to another structure: nested structures.

Example

a+b*c.



book(moby_dick,author(herman, melville)).



Parsing

Represent a syntax of an English sentence as a structure.

Simplified view:

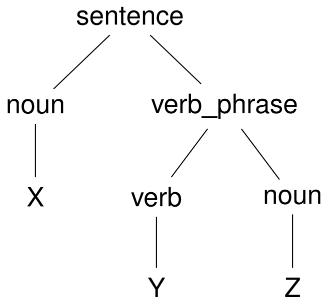
- Sentence: noun, verb phrase.
- Verb phrase: verb, noun.

Parsing

Structure:

sentence(noun(X),verb_phrase(verb(Y),noun(Z))).

Tree representation:

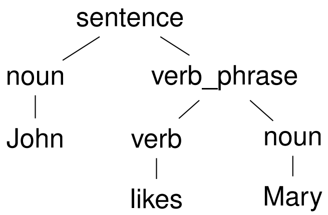


Parsing

Example

John likes Mary.

sentence(noun(John),verb_phrase(verb(likes),noun(Mary))).



Lists

- Very common data structure in nonnumeric programming.
- Ordered sequence of elements that can have any length.
  - Ordered: The order of elements in the sequence matters.
  - Elements: Any terms — constants, variables, structures — including other lists.
- Can represent practically any kind of structure used in symbolic computation.
- The only data structures in LISP — lists and constants.
- In PROLOG — just one particular data structure.

Lists

A list in PROLOG is either

- the empty list [ ], or
- a structure $.(h, t)$ where h is any term and t is a list.
  h is called the head and t is called the tail of the list $.(h, t)$.

Example

- $[]$.
- $.(a, [])$.
- $.(a, .(b, []))$.
- $.(a, .(a, .(1, [])))$.
- $.(.(f(a, X), []), .(X, []))$.
- $.([], [])$.

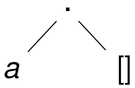
NB. $.(a, b)$ is a PROLOG term, but not a list!

Lists as Trees

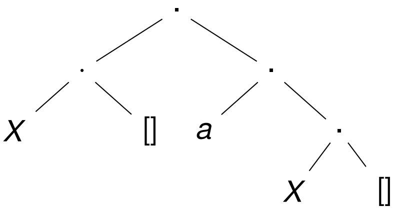
Lists can be represented as a special kind of tree.

Example

$.(a, [])$



$.(.(X, []), .(a, .(X, [])))$



List Notation

Syntactic sugar:

- Elements separated by comma.
- Whole list enclosed in square brackets.

Example

$.(a, [])$	$[a]$
$.(.(X, []), .(a, .(X, [])))$	$[[X], a, X]$
$.(.(X, []), .(.(a, .(X, [])), []))$	$[[X], [a, X]]$
$.([], [])$	$[[]]$

List Manipulation

Splitting a list L into head and tail:

- Head of L — the first element of L.
- Tail of L — the list that consists of all elements of L except the first.

Special notation for splitting lists into head and tail:

- $[X|Y]$, where X is head and Y is the tail.

NB. $[a|b]$ is a PROLOG term that corresponds to $.(a, b)$. It is not a list!

Head and Tail

Example

List	Head	Tail
$[a, b, c, d]$	a	$[b, c, d]$
$[a]$	a	$[]$
$[]$	(none)	(none)
$[[the, cat], sat]$	$[the, cat]$	$[sat]$
$[X + Y, x + y]$	$X + Y$	$[x + y]$

Unifying Lists

Example

Unifying Lists

Example

$$[X, Y, Z] \quad = \quad [\mathit{john}, \mathit{likes}, \mathit{fish}] \qquad X = \mathit{john},\ Y = \mathit{likes},\ Z = \mathit{fish}$$

Unifying Lists

Example

$$
\begin{array}{rcll}
[X, Y, Z] & = & [john, likes, fish] & X = john,\ Y = likes, \\
 & & & Z = fish \\
[cat] & = & [X|Y] & X = cat,\ Y = []
\end{array}
$$

Unifying Lists

Example

$$
\begin{array}{rcll}
[X, Y, Z] & = & [john, likes, fish] & X = john,\ Y = likes, \\
 & & & Z = fish \\
[cat] & = & [X|Y] & X = cat,\ Y = [] \\
[X, Y|Z] & = & [mary, likes, wine] & X = mary,\ Y = likes, \\
 & & & Z = [wine]
\end{array}
$$

Unifying Lists

Example

$$
\begin{array}{rcll}
[X, Y, Z] & = & [john, likes, fish] & X = john,\ Y = likes, \\
 & & & Z = fish \\
[cat] & = & [X|Y] & X = cat,\ Y = [] \\
[X, Y|Z] & = & [mary, likes, wine] & X = mary,\ Y = likes, \\
 & & & Z = [wine] \\
[[the, Y], Z] & = & [[X, hare], [is, here]] & X = the,\ Y = hare, \\
 & & & Z = [is, here]
\end{array}
$$

Unifying Lists

Example

$$
\begin{array}{rcll}
[X, Y, Z] & = & [john, likes, fish] & X = john,\ Y = likes, \\
 & & & Z = fish \\
[cat] & = & [X|Y] & X = cat,\ Y = [] \\
[X, Y|Z] & = & [mary, likes, wine] & X = mary,\ Y = likes, \\
 & & & Z = [wine] \\
[[the, Y], Z] & = & [[X, hare], [is, here]] & X = the,\ Y = hare, \\
 & & & Z = [is, here] \\
[[the, Y]|Z] & = & [[X, hare], [is, here]] & X = the,\ Y = hare, \\
 & & & Z = [[is, here]]
\end{array}
$$

Unifying Lists

Example

$[X, Y, Z]$	$=$	$[john, likes, fish]$	$X = john,\ Y = likes,\ Z = fish$
$[cat]$	$=$	$[X \mid Y]$	$X = cat,\ Y = []$
$[X, Y \mid Z]$	$=$	$[mary, likes, wine]$	$X = mary,\ Y = likes,\ Z = [wine]$
$[[the, Y], Z]$	$=$	$[[X, hare], [is, here]]$	$X = the,\ Y = hare,\ Z = [is, here]$
$[[the, Y] \mid Z]$	$=$	$[[X, hare], [is, here]]$	$X = the,\ Y = hare,\ Z = [[is, here]]$
$[golden \mid T]$	$=$	$[golden, norfolk]$	$T = [norfolk]$

Unifying Lists

Example

$[X, Y, Z]$	$=$	$[john, likes, fish]$	$X = john,\ Y = likes,$ $Z = fish$
$[cat]$	$=$	$[X \mid Y]$	$X = cat,\ Y = []$
$[X, Y \mid Z]$	$=$	$[mary, likes, wine]$	$X = mary,\ Y = likes,$ $Z = [wine]$
$[[the, Y], Z]$	$=$	$[[X, hare], [is, here]]$	$X = the,\ Y = hare,$ $Z = [is, here]$
$[[the, Y] \mid Z]$	$=$	$[[X, hare], [is, here]]$	$X = the,\ Y = hare,$ $Z = [[is, here]]$
$[golden \mid T]$	$=$	$[golden, norfolk]$	$T = [norfolk]$
$[vale, horse]$	$=$	$[horse, X]$	(none)

Unifying Lists

Example

$[X, Y, Z]$	$=$	$[john, likes, fish]$	$X = john,\ Y = likes,$ $Z = fish$
$[cat]$	$=$	$[X \mid Y]$	$X = cat,\ Y = []$
$[X, Y \mid Z]$	$=$	$[mary, likes, wine]$	$X = mary,\ Y = likes,$ $Z = [wine]$
$[[the, Y], Z]$	$=$	$[[X, hare], [is, here]]$	$X = the,\ Y = hare,$ $Z = [is, here]$
$[[the, Y] \mid Z]$	$=$	$[[X, hare], [is, here]]$	$X = the,\ Y = hare,$ $Z = [[is, here]]$
$[golden \mid T]$	$=$	$[golden, norfolk]$	$T = [norfolk]$
$[vale, horse]$	$=$	$[horse, X]$	(none)
$[white \mid Q]$	$=$	$[P \mid horse]$	$P = white,\ Q = horse$

Strings are Lists

- PROLOG strings — character string enclosed in double quotes.
- Examples: "This is a string", "abc", "123", etc.
- Represented as lists of integers that represent the characters (ASCII codes)
- For instance, the string "system" is represented as $[115, 121, 115, 116, 101, 109]$.

Membership in a List

`member(X,Y)` is true when X is a member of the list Y.

One of two conditions:

1. X is a member of the list if X is the same as the head of the list
   ```
   member(X,[X|_]).
   ```
2. X is a member of the list if X is a member of the tail of the list
   ```
   member(X,[_|Y]) :- member(X,Y).
   ```

Recursion

- First Condition is the *boundary condition*.
  (A hidden boundary condition is when the list is the empty list, which fails.)
- Second Condition is the *recursive case*.
- In each recursion the list that is being checked is getting smaller until the predicate is satisfied or the empty list is reached.

Member Success

```
?- member(a,[a,b,c]).
 Call:   (8) member(a,[a,b,c]) ?
 Exit:   (8) member(a,[a,b,c]) ?
Yes

?- member(b,[a,b,c]).
 Call:   (8) member(b,[a,b,c]) ?
 Call:   (9) member(b,[b,c]) ?
 Exit:   (9) member(b,[b,c]) ?
 Exit:   (8) member(b,[a,b,c]) ?
Yes
```

Member Failure

```
?- member(d,[a,b,c]).
 Call:   (8) member(d,[a,b,c]) ?
 Call:   (9) member(d,[b,c]) ?
 Call:   (10) member(d,[c]) ?
 Call:   (11) member(d,[]) ?
 Fail:   (11) member(d,[]) ?
 Fail:   (10) member(d,[c]) ?
 Fail:   (9) member(d,[b,c]) ?
 Fail:   (8) member(d,[a,b,c]) ?
No
```

Member. Questions

What happens if you ask PROLOG the following questions:

```
?- member(X,[a,b,c]).
?- member(a,X).
?- member(X,Y).
?- member(X,_).
?- member(_,Y).
?- member(_,_).
```

Recursion. Termination Problems

- Avoid circular definitions. The following program will loop on any goal involving `parent` or `child`:

```
parent(X,Y):-child(Y,X).
child(X,Y):-parent(Y,X).
```

- Use left recursion carefully. The following program will loop on `?- person(X)`:

```
person(X):-person(Y),mother(X,Y).
person(adam).
```

Recursion. Termination Problems

- Rule order matters.
- General heuristics: Put facts before rules whenever possible.
- Sometimes putting rules in a certain order works fine for goals of one form but not if goals of another form are generated:

  ```
  islist([_|B]):-islist(B).
  islist([]).
  ```

  works for goals like `islist([1,2,3])`, `islist([])`, `islist(f(1,2))` but loops for `islist(X)`.
- What will happen if you change the order of `islist` clauses?

Recursion

- Weak version of `islist`.

```
weak_islist([]).
weak_islist([_|_]).
```

- Can it loop?
- Does it always give the correct answer?

Mapping?

- Goal: Construct a new structure from the old one.
- The new structure should be similar to the old one but changed in some way

Map a given structure to another structure given a set of rules:

1. Traverse the old structure component by component.
2. Construct the new structure with transformed components.

Mapping a Sentence to Another

Example

you are a computer maps to a reply i am not a computer.
do you speak french maps to a reply no i speak german.

Procedure:

1. Accept a sentence.
2. Change you to i.
3. Change are to am not.
4. Change french to german.
5. Change do to no.
6. Leave the other words unchanged.

Mapping a Sentence. PROLOG Program

Example

```
change(you,i).
change(are,[am,not]).
change(french,german).
change(do,no).
change(X,X).

alter([],[]).
alter([H|T],[X|Y]) :-
  change(H,X),
  alter(T,Y).
```

Boundary Conditions

- Termination: `alter([],[]).`
- Catch all (If none of the other conditions were satisfied, then just return the same): `change(X,X).`