CSc 520

Principles of Programming Languages

42 : Logic Programming — Prolog Basic

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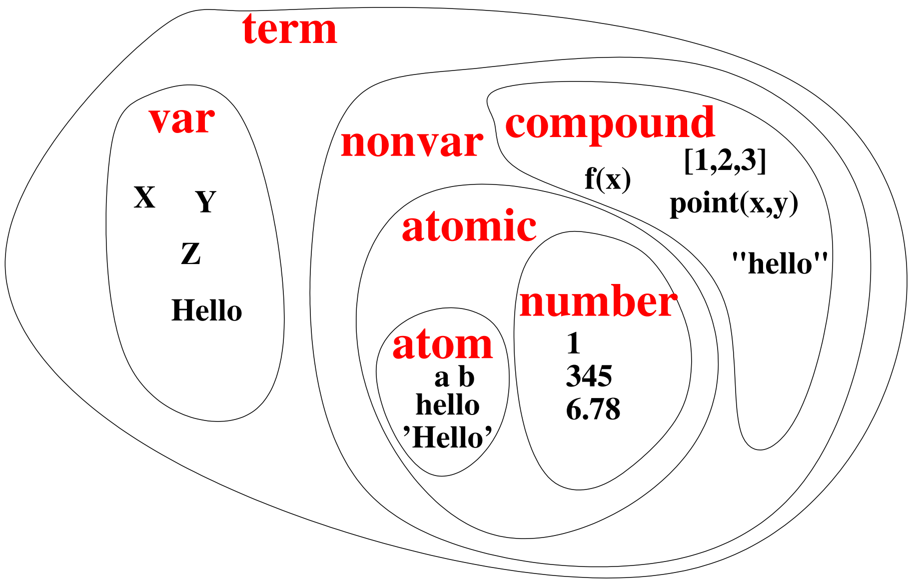
Prolog Types

- The term is Prolog's basic data structure.
- Everything is expressed in the form of a term. This includes programs and data.
- Prolog has four basic types of terms:
  1. variables start with an uppercase letter;
  2. compound terms are lists, strings, and structures;
  3. atoms start with a lower-case letter;
  4. numbers.

Prolog Types. . .



Prolog Numbers

- Most Prolog implementations support infinite precision integers. This is not true of GNU Prolog!
- The built-in operator is evaluates arithmetic expressions:

```
| ?- X is 6*7.
X = 42
| ?- X is 6.0*7.0.
X = 42.0
| ?- X is 6000000000000*7000000000000000.
X = 1
```

Prolog Arithmetic Expressions

- An infix expression is just shorthand for a structure:

```
| ?- X = +(1,*(2,3)).
X = 1+2*3
| ?- X = 1+2*3.
X = 1+2*3
| ?- X is +(1,*(2,3)).
X = 7
| ?- X is 1+2*3.
X = 7
```

- X = 1*2 means "make the variable X and 1*2 the same". It looks like an assignment, but it's what we call unification. More about that later.

Prolog Atoms

- Atoms are similar to `enum`s in C.
- Atoms start with a lower-case letter and can contain letters, digits, and underscore (_).

```
| ?- X = hello.
X = hello
| ?- X = hE_l_l_o99.
X = hE_l_l_o99
```


Prolog Variables

- Variables start out uninstantiated, i.e. without a value.
- Uninstantiated variables are written `_number`:

```
| ?- write(X).
_16
```

- Once a Prolog variable has been instantiated (given a value), it will keep that value.

```
| ?- X=sally.
X = sally
| ?- X=sally, X=lisa.
no
```


Prolog Variables...

- When a program backtracks over a variable instantiation, the variable again becomes uninstantiated.

```
| ?- (X=sally; X=lisa), write(X), nl.
sally
X = sally ? ;

lisa
X = lisa
```

Prolog Programs

- A Prolog program consists of a database of facts and rules:

```
likes(lisa,chocolate).
likes(lisa,X) :- tastes_like_chocolate(X).
```

- `:-` is read if.
- `:-` is just an operator, like other Prolog operators. The following are equivalent:

```
likes(lisa,X) :- boy(X),tastes_like_choc(X).

:-(likes(lisa,X),
   (boy(X),tastes_like_chok(X))).
```


Prolog Programs...

- Prolog facts/rules can be overloaded, wrt their arity.
- You can have a both a rule `foo()` and a rule `foo(X)`:

```
| ?- [user].
foo.
foo(hello).
foo(bar,world).
foo(X,Y,Z) :-
    Z is X + Y.
<ctrl-D>
```

```
| ?- foo.
yes
| ?- foo(X).
X = hello
| ?- foo(X,Y).
X = bar
Y = world
| ?- foo(1,2,Z).
Z = 3
```


Standard predicates

- `read(X)` and `write(X)` read and write Prolog terms.
- `nl` prints a newline character.

```
| ?- write(hello),nl.
hello

| ?- read(X), write(X), nl.
hello.
hello
```


Standard predicates...

- `write` can write arbitrary Prolog terms:

```
| ?- write(hello(world)),nl.
hello(world)
```

- Note that `read(X)` requires the input to be syntactically correct and to end with a period.

```
| ?- read(X).
foo).
uncaught exception:  error
```

Unification/Matching

- The = -operator tries to make its left and right-hand sides the same.
- This is called unification or matching.
- If Prolog can't make X and Y the same in X = Y, matching will fail.

```
| ?- X=lisa, Y=sally, X = Y.
no
| ?- X=lisa, Y=lisa, Z = X, Z = Y.
X = lisa
Y = lisa
Z = lisa
```

- We will talk about this much more later.

Backtracking

- Prolog will try every possible way to satisfy a query.
- Prolog explores the search space by using backtracking, which means undoing previous computations, and exploring a different search path.

Backtracking. . .

- Here's an example:

```
| ?- [user].
girl(sally).
girl(lisa).
pretty(lisa).
blonde(sally).
| ?- girl(X),pretty(X).
X = lisa
| ?- girl(X),pretty(X),blonde(X).
no
| ?- (X=lisa; X=sally), pretty(X).
X = lisa
```

- We will talk about this much more later.

Māori Family Relationships

John Foster (in *He Whakamaarama – A New Course in Māori*) writes:

> Relationship is very important to the Māori. Social seniority is claimed by those able to trace their whakapapa or genealogy in the most direct way to illustrious ancestors. Rights to shares in land and entitlement to speak on the marae may also depend on relationship. Because of this, there are special words to indicate elder or younger relations, or senior or younger branches of a family.

- Māori is the indigenous language spoken in New Zealand. It is a polynesian language, and closely related to the language spoken in Hawaii.

Māori Terms of Address

Māori	English
au	I
tipuna, tupuna	grandfather, grandmother, grandparent, ancestor
tiipuna	grandparents
matua taane	father
maatua	parents
paapaa	father
whaea, maamaa	mother
whaea kee	aunt
kuia	grandmother, old lady
tuakana	older brother of a man, older sister of a woman
teina	younger brother of a man, younger sister of a woman

Māori Terms of Address. . .

Māori	English
tungaane	woman's brother (older or younger)
tuahine	man's sister (older or younger)
kaumaatua	elder (male)
mokopuna	grandchild (male or female)
iraamutu	niece, nephew
taane	husband, man
hunaonga	daughter-in-law, son-in-law
tamaahine	daughter
tama	son
tamaiti	child (male or female)
tamariki	children
wahine	wife, woman
maataamua	oldest child

Māori Terms of Address. . .

Māori	English
pootiki	youngest child
koroheke, koro, koroua	old man
whaiapo	boyfriend, girlfriend[a]
kootiro	girl
tamaiti taane	boy
whanaunga	relatives

[a] Literally: "What you follow at night"

The Whanau

- A program to translate between English and Māori must take into account the differences in terms of address between the two languages.
- Write a Prolog predicate `calls(X,Y,Z)` which, given a database of family relationships, returns **all** the words that `X` can use to address or talk about `Y`.

```
?- calls(aanaru, hata, Z).
   Z = tuakana ;
   Z = maataamua ;
   no

?- calls(aanaru, rapeta, Z).
   Z = teina ;
   no
```

The Whanau…

- Whanau is Māori for family.
- Below is a table showing an extended Māori family.

Name	Sex	Father	Mother	Spouse	Born
Hoone	male	unknown	unknown	Rita	1910
Rita	female	unknown	unknown	Hone	1915
Ranginui	male	unknown	unknown	Reremoana	1915
Reremoana	female	unknown	unknown	Ranginui	1916
Rewi	male	Hoone	Rita	Rahia	1935
Rahia	female	Ranginui	Reremoana	Rewi	1940
Hata	male	Rewi	Rahia	none	1957
Kiri	female	Rewi	Rahia	none	1959

The Whanau…

Name	Sex	Father	Mother	Spouse	Born
Hiniera	female	Rewi	Rahia	Pita	1960
Aanaru	male	Rewi	Rahia	none	1962
Rapeta	male	Rewi	Rahia	none	1964
Mere	female	Rewi	Rahia	none	1965
Pita	male	unknown	unknown	Hiniera	1960
Moeraa	female	Pita	Hiniera	none	1986
Huia	female	Pita	Hiniera	none	1987
Irihaapeti	female	Pita	Hiniera	none	1988

The Whanau Program — Database Facts

- We start by encoding the family as facts in the Prolog database.

```
% person(name,   sex,      father,mother,spouse,    birth-year).

person(hoone,    male,     unkn1, unkn5, rita,      1910).
person(rita,     female,   unkn2, unkn6, hoone,     1915).
person(ranginui,male,      unkn3, unkn7, reremoana,1915).
person(reremoana, female,unkn4, unkn8, ranginui, 1916).

person(rewi,  male,    hoone,    rita,      reremoana, 1935).
person(rahia, female, ranginui, reremoana, rita,       1916).

person(hata,     male,     rewi,  rahia,  none,    1957).
person(kiri,     female,   rewi,  rahia   none,    1959).
```


The Whanau Program — Database Facts. . .

```
% person(name,   sex,      father,mother,spouse,    birth-year).
person(hiniera, female,  rewi,  rahia,  pita,    1960).
person(anaru,    male,     rewi,  rahia,  none,    1962).
person(rapeta,   male,     rewi,  rahia,  none,    1964).
person(mere,     female,  rewi,  rahia,  none,    1965).
person(pita,     male,     unkn9, unkn10, hiniera,1960).

person(moeraa,  female,    hiniera,  pita, none, 1986).
person(huia,     female,    hiniera,  pita, none, 1987).
person(irihaapeti, female,hiniera,  pita, none, 1988).
```

Whanau — Auxiliary predicates

- We introduce some auxiliary predicates to extract information from the database.

```
% Auxiliary predicates
gender(X, G) :- person(X, G, _, _, _, _).
othergender(male, female).
othergender(female, male).
female(X) :- gender(X, female).
male(X)   :- gender(X, male).
```


Whanau — Family Relationships

- We next write some predicates that computes common family relationships.

```
% Is Y the <operator> of X?
wife(X, Y)     :- person(X, male, _, _, Y, _).
husband(X, Y) :- person(X, female, _, _, Y, _).
spouse(X, Y)  :- wife(X, Y).
spouse(X, Y)  :- husband(X, Y).
parent(X, Y)  :- person(X, _,Y, _, _, _).
parent(X, Y)  :- person(X, _,  _, Y, _, _).
son(X, Y)     :- person(Y, male, X, _, _, _).
son(X, Y)     :- person(Y, male, _, X, _, _).
daughter(X, Y):- person(Y, female, X, _, _, _).
daughter(X, Y):- person(Y, female, _, X, _, _).
child(X, Y)   :- son(X, Y).
child(X, Y)   :- daughter(X, Y)
```


Whanau — Family Relationships. . .

- Some of the following are left as an exercise:

```
% Is X older than Y?
older(X,Y) :-
      person(X, _, _, _, _,Xyear),
      person(Y, _, _, _, _,Yyear),
      Yyear > Xyear.

% Is Y a sibling of X of the gender G?
sibling(X, Y, G) :- <left as an exercise>.

% Is Y one of X's older siblings of gender G?
oldersibling(X,Y,G) :- <left as an exercise>.

% Is Y one of X's older/younger siblings of either gender?
oldersibling(X,Y) :- <left as an exercise>.
youngersibling(X,Y) :- <left as an exercise>.
```


Whanau — Family Relationships. . .

```
% Is Y an ancestor of X of gender G?
ancestor(X,Y,G) :- <left as an exercise>.

% Is Y an older relative of X of gender G?
olderrelative(X,Y,G) :-
   ancestor(X, Y, G).
olderrelative(X,Y,G) :-
   ancestor(X, Z, _),
   sibling(Y, Z, G).

% Is Y a sibling of X of his/her opposite gender?
siblingofothersex(X, Y) :- <left as an exercise>.
```

The Whanau Program — Calls

- We can now finally write the predicate `calls(X,Y,T)` which computes all the ways `T` in which `X` can address `Y`.

```
% Me.
calls(X, X, au).

% Parents.
calls(X,Y,paapaa) :- person(X, _,Y, _, _, _).
calls(X,Y,maamaa) :- person(X, _, _,Y, _, _).

% Oldest/youngest sibling of same sex.
calls(X, Y, tuakana) :-
   gender(X, G),
   eldestsibling(X, Y, G).
calls(X, Y, teina) :-
   gender(X, G),
   youngestsibling(X, Y, G).
```


The Whanau Program — Calls. . .

```
% Siblings of other sex.
calls(X, Y, tungaane) :- <left as an exercise>.
calls(X, Y, tuahine) :- <left as an exercise>.
calls(X, Y, tipuna) :-  <left as an exercise>.

% Sons and daughters.
calls(X, Y, tama)    :-  <left as an exercise>.
calls(X, Y, tamahine) :-  <left as an exercise>.

% Oldest/youngest child.
calls(X, Y, maataamua) :- <left as an exercise>.
calls(X, Y, pootiki) :- <left as an exercise>.

% Child-in-law.
calls(X, Y, hunaonga) :-  <left as an exercise>.

% Grandchild.
calls(X, Y, mokopuna) :-  <left as an exercise>.
```


Readings and References

- Read Clocksin-Mellish, Chapter 2.