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Introduction

Lecture 1, 13th Oct 2025 // Foundations of Logic Programming, WS 2025/26

Overview

Prolog Programs

Queries

Advantages of Declarative Programs

Shortcomings of Prolog

How to Use a Prolog System

Prolog Programs

A Prolog Program

```
direct(frankfurt,san_francisco).  
direct(frankfurt,chicago).  
direct(san_francisco,honolulu).  
direct(honolulu,maui).
```

Facts

```
connection(X, Y) :- direct(X, Y).  
connection(X, Y) :- direct(X, Z), connection(Z, Y).
```

Rules

Queries

Queries (1)

```
direct(frankfurt,san_francisco).  
direct(frankfurt,chicago).  
direct(san_francisco,honolulu).  
direct(honolulu,maui).
```

```
connection(X, Y) :- direct(X, Y).  
connection(X, Y) :- direct(X, Z), connection(Z, Y).
```

```
| ?- connection(frankfurt, maui).
```

yes

Queries (2)

```
direct(frankfurt,san_francisco).  
direct(frankfurt,chicago).  
direct(san_francisco,honolulu).  
direct(honolulu,maui).
```

```
connection(X, Y) :- direct(X, Y).  
connection(X, Y) :- direct(X, Z), connection(Z, Y).
```

```
| ?- connection(san_francisco, X).
```

```
X = honolulu ;
```

```
X = maui ;
```

```
no
```

Queries (3)

```
direct(frankfurt,san_francisco).  
direct(frankfurt,chicago).  
direct(san_francisco,honolulu).  
direct(honolulu,maui).
```

```
connection(X, Y) :- direct(X, Y).  
connection(X, Y) :- direct(X, Z), connection(Z, Y).
```

```
| ?- connection(maui, X).
```

no

An Important Data Structure: Lists

$[a_1, \dots, a_n]$
 $[head \mid tail]$

$[apples, pears, plums]$
 $[apples \mid [pears, plums]]$

`member(X, [X | List]).`

`member(X, [Y | List]) :- member(X, List).`

`member_both(X, L1, L2) :- member(X, L1), member(X, L2).`

`| ?- member_both(X, [apples,pears,plums], [peaches,plums,pears]).`

`X = pears ;`

`X = plums ;`

`no`

Advantages of Declarative Programs

An Imperative Program for Comparison

```
function members(a: number[], b: number[]): number[] {  
  
    let c: number[] = [];  
    let i, j: number;  
  
    for (i = 0; i < a.length; i += 1) {  
        for (j = 0; j < b.length; j += 1) {  
            if (a[i] == b[j]) {  
                c.push(a[i]);  
            }  
        }  
    }  
  
    return c;  
}
```

Declarative Programs are Flexible

```
member(X, [X | List]).  
member(X, [_ | List]) :- member(X, List).
```

```
member_both(X, L1, L2) :- member(X, L1), member(X, L2).
```

```
| ?- member_both(pears, [apples, pears, plums], [peaches, plums, pears]).
```

yes

```
| ?- member_both(apples, [apples, pears, plums], [peaches, X]).
```

X = apples

Declarative Programs are Flexible

`add(X, 0, X).`

`add(X, s(Y), s(Z)) :- add(X, Y, Z).`

`| ?- add(s(0), s(0), Z).`

`Z = s(s(0))`

`| ?- add(X, Y, s(s(0))).`

`X = s(s(0)),`

`Y = 0 ;`

`X = s(0),`

`Y = s(0) ;`

`X = 0,`

`Y = s(s(0))`

Yet Another Program

The square of 45 is 2025, and $20 + 25$ is 45, isn't that strange?
Find more pairs of numbers that exhibit this peculiarity!

```
solution(N, Z) :- between(1, 99, N),  
Z is N*N,  
Z >= 1000,  
(Z // 100) + (Z mod 100) := N.  
  
| ?- solution(N, Z).
```

N = 45, Z = 2025 ;

N = 55, Z = 3025 ;

N = 99, Z = 9801

Quiz: Program and Queries

Quiz

Consider this program:

```
mother(mary, harry).      mother(edna, wilma).  
father(eddy, harry).      father(eddy, wilma).
```

```
siblings(X, Y) :- mother(M, X), mother(M, Y).  
siblings(X, Y) :- father(F, X), father(F, Y).
```

...

Programming Languages

▷ Imperative Programming Languages

- declaration part defines possible states (of variables); statement part defines transformation on states
- close to von Neumann computer architecture
- description of *how* something is computed
- Example languages: C/C++, Java, Python

▷ Declarative Programming Languages

- abstraction from states and state transformations
- direct formulation of mathematical objects (functions, relations, constraints)
- description of *what* is computed
- Example languages: Haskell, Prolog, Scala, Curry, Eclipse Prolog

Declarative Programming Languages

- ▷ Functional Programming Languages
Example language: Haskell
- ▷ Logic Programming Languages
Example language: Prolog
- ▷ Integrated (Functional-logic) Programming Languages
Example language: Curry
- ▷ Constraint Logic Programming Languages
Example language: Eclipse Prolog

Advantages of Declarative Programming

- ▷ Specifications are programs.
- ▷ The computation mechanism is not part of the program.
- ▷ 'Thinking' declaratively is easier than 'thinking' procedurally.
- ▷ Declarative programs are therefore much simpler to understand, to develop, and to prove properties about.
- ▷ The output of a logic program is a logical consequence of the program.
- ▷ Flexibility of logic programs.

Shortcomings of Prolog

Shortcomings of Prolog: Termination (1)

```
direct(frankfurt,san_francisco).  
direct(frankfurt,chicago).  
direct(san_francisco,honolulu).  
direct(honolulu,maui).
```

```
direct(san_francisco,san_francisco).
```

```
connection(X, Y) :- direct(X, Y).  
connection(X, Y) :- direct(X, Z), connection(Z, Y).
```

```
| ?- connection(san_francisco, X).
```

```
X = honolulu ;
```

```
X = san_francisco ;
```

```
X = maui ;
```

```
X = honolulu ;
```

```
...
```

Shortcomings of Prolog: Termination (2)

```
direct(san_francisco,san_francisco).
```

```
direct(frankfurt,san_francisco).
```

```
direct(frankfurt,chicago).
```

```
direct(san_francisco,honolulu).
```

```
direct(honolulu,maui).
```

```
connection(X, Y) :- direct(X, Y).
```

```
connection(X, Y) :- direct(X, Z), connection(Z, Y).
```

```
| ?- connection(san_francisco, X).
```

```
X = san_francisco ;
```

```
X = honolulu ;
```

```
X = san_francisco ;
```

```
X = honolulu ;
```

```
...
```

Shortcomings of Prolog: Termination (3)

```
direct(frankfurt,san_francisco).  
direct(frankfurt,chicago).  
direct(san_francisco,honolulu).  
direct(honolulu,maui).  
direct(san_francisco,san_francisco).
```

```
connection(X, Y) :- direct(X, Z), connection(Z, Y).  
connection(X, Y) :- direct(X, Y).
```

```
| ?- connection(san_francisco, X).
```

```
X = maui ;  
X = maui ;  
X = maui ;  
...
```

Shortcomings of Prolog: Termination (4)

```
direct(san_francisco,san_francisco).
```

```
direct(frankfurt,san_francisco).
```

```
direct(frankfurt,chicago).
```

```
direct(san_francisco,honolulu).
```

```
direct(honolulu,maui).
```

```
connection(X, Y) :- direct(X, Z), connection(Z, Y).
```

```
connection(X, Y) :- direct(X, Y).
```

```
| ?- connection(san_francisco, X).
```

?

Shortcomings of Prolog: Occur Check

A person x and the mother of x can never be the same.

```
mystery :- same_person(X, mother_of(X)).
```

```
same_person(Z, Z).
```

```
| ?- mystery.
```

```
yes
```

Shortcomings of Prolog: Is it truly declarative?

This rule can only be “called” if all three arguments are numbers:

```
between(X, Y, Z) :- X =< Z, Z =< Y.
```

This is the “simplest” usable specification:

```
between(X, Y, Z) :- X =< Y, Z is X.
```

```
between(X, Y, Z) :- X < Y, X1 is X+1, between(X1, Y, Z).
```

How to Use a Prolog System

How to Use a Prolog System (1)

```
irz601: > cat add.pl
```

```
add(X,0,X).
```

```
add(X,s(Y),s(Z)) :- add(X,Y,Z).
```

```
irz601: > sicstus
```

```
SICStus 3 #5: Fri Nov 1 15:49:55 MET 1996
```

```
| ?- [add].
```

```
consulting /usr/users/ith/ak15/add.pl...
```

```
/usr/users/ith/ak15/add.pl consulted, 0 msec 352 bytes
```

```
yes
```

```
| ?- add(X,Y,s(s(0))).
```

How to Use a Prolog System (2)

```
X = s(s(0)),  
Y = 0 ? ;
```

```
X = s(0),  
Y = s(0) ? ;
```

```
X = 0,  
Y = s(s(0)) ? ;
```

```
no  
| ?- halt.
```

Conclusion

Summary

- Prolog programs consist of **facts** and **rules**.
- We use Prolog by asking **queries** to programs.
- Answers to queries can be Boolean (yes/no) ...
- ...or given by variable assignments.
- Prolog programs are **declarative** (to a certain extent).

Suggested action points:

- Prolog interpreters are freely available – install one now, e.g. on ubuntu:
`sudo apt install swi-prolog`
- ...or other platforms: <https://www.swi-prolog.org/download/stable>
- Try out the examples of this lecture.