Logic Programming in Prolog with tuProlog

Distributed Systems / Technologies

Sistemi Distribuiti / Tecnologie

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Academic Year 2016/2017

1. Lab Activity 1
2. Prolog
3. Lab Activity 2

Next in Line...

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3. Lab Activity 2

Example 1: The `parent.pl` Knowledge Base I

```
parent(joey,luca).
parent(joey,simone).
parent(lino,joey).
parent(mirella,joey).
```

A logic theory

- a simple logic *program*
- with four *ground facts*
- representing one sort of relation between elements of the *domain of discourse*

? is there anything we can do with this program?

?? can we *compute* anything?

Example 1: The `parent.pl` Knowledge Base II

Constants & predicates

- `joey`, `luca`, `simone`, `lino` and `mirella` are *constant* used in the program as *ground terms* to denote the element of the domain
- `parent` is the *predicate* used in the program to talk about the domain of discourse—`parent/2` says that `parent` is the *predicate symbol* with *arity* 2

Example 1: The `parent.pl` Knowledge Base III

Goals

- since the only predicate in the program is `parent/2`, we cannot prove anything else, in principle—except for tautologies, or built-in Prolog predicates
- possible goals
  1. `:- parent(joey,luca).`
  2. `:- parent(joey,lino).`
  3. `:- parent(joey,X).`
  4. `:- parent(X,joey).`
  5. `:- parent(X,Y).`

Let us try the above *queries* in tuProlog

tuProlog in Short I

What is tuProlog?

- tuProlog is a light-weight Prolog system for distributed applications and infrastructures [Denti et al., 2001]
- intentionally designed around a minimal core
- to be either statically or dynamically *configured* by loading/unloading libraries of predicates
- tuProlog natively supports multi-paradigm programming [Denti et al., 2005], providing a clean, seamless integration model between Prolog and mainstream object-oriented languages

tuProlog in Short II

Where is tuProlog?

UniBo `http://tuprolog.unibo.it`

BitBucket `http://bitbucket.org/tuprologteam/tuprolog`

downloads `http://bitbucket.org/tuprologteam/tuprolog/downloads`

tuProlog in Short III

What to download?

From `http://bitbucket.org/tuprologteam/tuprolog/downloads`

v. 3.0.1 `http://bitbucket.org/tuprologteam/tuprolog/downloads/2p-3.0.1.zip`

guide `http://bitbucket.org/tuprologteam/tuprolog/downloads/tuprolog-guide-3.0.pdf`

Let us try the above *queries* in tuProlog

Interactive Programming in Prolog I

Starting tuProlog CLI

- after downloading the tuProlog ZIP file, unzip it, and position your command line in the `2p-3.0.1/bin/` directory
- then invoke the tuProlog command line interface (CLI) with

```
java -cp 2p.jar alice.tuprologx.ide.CUIConsole
```

- to see if everything is working, invoke query

```
?- write('Hello, World!').
```

and see what happens

Interactive Programming in Prolog II

- first, load a simple program with the query

```
?- set_theory('parent(joey,luca). parent(joey,simone).
   parent(lino,joey). parent(mirella,joey).').
```

- then try the following queries:
  1. `?- parent(joey,luca).`
  2. `?- parent(joey,lino).`
  3. `?- parent(joey,X).`
  4. `?- parent(X,joey).`
  5. `?- parent(X,Y).`

  and see what happens, by responding with
  - ⟨return⟩ to accept the answer
  - ; to have more answers

Interactive Programming in Prolog III

Remarks on interaction

1. success
2. failure
3. computed substitution
4. unification
5. backtracking

all no input / output parameters: no *direction* required for arguments in principle thanks to unification

tuProlog GUI

Starting tuProlog GUI

- in the same `2p-3.0.1/bin/` directory as before, invoke the tuProlog graphical user interface (GUI) with

  ```
  java -cp 2p.jar alice.tuprologx.ide.GUILauncher
  ```

- to see if everything is working, invoke query

  ```
  ?- write('Hello, World!').
  ```

  and see what happens
- redo `parent.pl` experiments with GUI
  - load `parent.pl`
  - retry the queries discussed in the CLI experiments

Example 2: grandparent.pl

Adding a rule

- load `grandparent.pl`
- there, rule

  ```
  grandparent(X,Z) :- parent(X,Y), parent(Y,Z).
  ```

  is added to the knowledge base
- now the logic program is a collection of *facts* and *rules*
- ! it is a so-called *universal rule*

Test the program

- now try the following queries:
  1. `?- grandparent(lino,luca).`
  2. `?- grandparent(lino,joey).`
  3. `?- grandparent(joey,X).`
  4. `?- grandparent(lino,X).`
  5. `?- grandparent(X,Y).`

Example 3: `sibling.pl`

Adding another rule

- load `sibling.pl`
- there, rule

  ```
  sibling(Y,Z) :- parent(X,Y), parent(X,Z).
  ```

  is added to the previous logic theory
- all the previous theorems are true: all previous computations are the same
- just adding new theorems based on a new rule

! operator `\=/2` represent an *explicit* computation over terms

- succeeding when the two arguments are terms that do not unify
- all other computations over terms till now were *implicitly* driven by goal unification

Test the program

- now try the following queries:

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Prolog Syntax I

Prolog terms

variables alphanumeric strings starting with either an *uppercase* letter or an *underscore*

- underscore alone is the *anonymous variable*—sort of *don't care* variable
- underscore followed by a string is a normal variable during resolution, but it does not need to be exposed in the computed substitution

functors alphanumeric strings starting with a *lowercase* letter

- holds for both proper functors and constants

terms are built recursively out of functors and variables as in logic programming

→ e.g., `term`, `Var`, `f(X)`, `p(Y,f(a))` are *Prolog terms*

→ e.g., `term`, `f(a)`, `p(x,y)` are *Prolog ground terms*

Prolog Syntax II

Prolog atoms

predicates alphanumeric strings starting with a *lowercase* letter

- the same as functors

atoms are built applying predicates to terms as in logic programming

→ e.g., `predicate`, `f(X)`, `p(Y,f(a))` are *Prolog atoms*

→ e.g., `predicate`, `f(a)`, `p(x,y)` are *Prolog ground atoms*

Towards meta-programmings

- `parent(lino,joey)` – out of context – could represent either a ground atom or a ground term
- is this an issue or a feature?
- it paves the way towards *meta-programming*

Prolog Syntax III

Prolog clauses

clause a Horn clause of the form `A :- B1, ..., Bn.`

- where `A, B1, ..., Bn` are Prolog atoms
- `A` is the head of the clause
- `B1, ..., Bn` is the body of the clause
- `:-` denotes logic implication
- `.` is the terminator

fact a clause with no body `A.` ($n = 0$)

rule a clause with at least one atom in the body
`A :- B1, ..., Bn.` ($n > 0$)

goal a clause with no head and at least one atom in the body
`:- B1, ..., Bn.` ($n > 0$)

- often written as `?- B1, ..., Bn.`

Prolog Syntax IV

Prolog program

program	a sequence of Prolog clauses
	interpreted as a *conjunction* of clauses
logic theory	constituting a *logic theory* made of Horn clauses written according the Prolog syntax

Prolog Execution I

Aim of a Prolog computation

- given a Prolog program P and the goal `?- p(t1,t2,...,tm)` (also called *query*)
- if `X1,X2,...,Xn` are the variables in terms `t1,t2,...,tm`
- the meaning of the goal is to query P and find whether there are some values for `X1,X2,...,Xn` that make `p(t1,t2,...,tm)` true

$\rightarrow$ thus, the aim of the Prolog computation is to find a substitution $\sigma =$`X1/s1,X2/s2,...,Xn/sn` such that $P \models \texttt{p(t1,t2,...,tm)}\sigma$

Prolog Execution II

Prolog search strategy

- as a logic programming language, Prolog adopts SLD resolution
- as a search strategy, Prolog applies resolution in a strictly linear fashion
  - *goals* are replaced *left-to-right*, sequentially
  - *clauses* are considered in *top-to-bottom* order
  - *subgoals* are considered *immediately* once set up

$\rightarrow$ resulting in a *depth-first* search strategy

Prolog Execution III

Prolog backtracking

- in order to achieve completeness, Prolog saves *choicepoints* for any possible alternative still to be explored
- and goes back to the nearest choice point available in case of failure
- exploiting automatic backtracking

Next in Line...

1 Lab Activity 1

2 Prolog

3 Lab Activity 2

Types in LP

No types in LP

- in pure LP 3 and + are just symbols, with no specific meaning attached
- and, in pure Prolog as well

? how do we deal, e.g., with natural numbers?

! Giuseppe Peano shows us the way

Natural Numbers in Logic I

Peano axioms

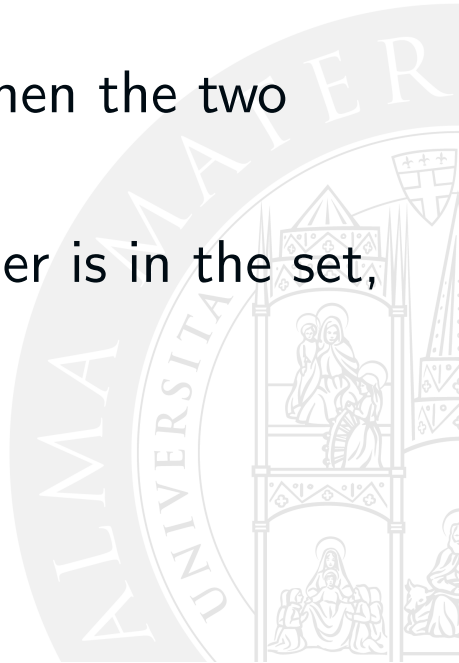
http://www.britannica.com/topic/Peano-axioms

Peano axioms, also known as Peano's postulates, in number theory, five axioms introduced in 1889 by Italian mathematician Giuseppe Peano. Like the axioms for geometry devised by Greek mathematician Euclid (c. 300 bce), the Peano axioms were meant to provide a rigorous foundation for the natural numbers (0, 1, 2, 3, . . .) used in arithmetic, number theory, and set theory. In particular, the Peano axioms enable an infinite set to be generated by a finite set of symbols and rules.

Natural Numbers in Logic II

The five Peano axioms are

1. zero is a natural number
2. every natural number has a successor in the natural numbers
3. zero is not the successor of any natural number
4. if the successor of two natural numbers is the same, then the two original numbers are the same
5. if a set contains zero and the successor of every number is in the set, then the set contains the natural numbers



Natural Numbers in LP I

How do we represent natural numbers in LP?

- in LP
  - the *Herbrand Universe* represents the elements of the domain of discourse
  - the *Herbrand Base* represents the elementary propositions over the domain of discourse

→ in order to represent natural numbers in LP, we use

- *constants* and *functors* for natural numbers
- *predicates* for relations such as $n \in \mathbb{N}$

Natural Numbers in LP II

Constants & functors

- our domain of discourse is $\mathbb{N}$, the set of *natural numbers*
- our Herbrand Universe needs to express the elements of $\mathbb{N}$
- from Peano axioms, we understand that
  - zero is essential
    - `z` we use `z` as the *constant* symbol for *zero*
    - ! it is not something belonging to the language: it is just our *(pre-)interpretation* of symbol `z` for our current purposes
  - the notion of successor is essential, too
    - `s/1` we use `s/1` (`s` with arity 1) as the *functor* symbol for *successor*
    - → if `N` is a natural number, then `s(N)` is another natural number—precisely, the *successor* of `N`
      - *recursive data structure*: the successor of `s(N)` is `s(s(N))`, which is another natural number

e.g. in our pre-interpretation, `z` is zero, `s(z)` is one, `s(s(z))` is two, ...

Natural Numbers in LP III

Predicates

- we focus on the simple relation $n \in \mathbb{N}$—that is, n is a natural number

nat/1 we use `nat/1` (`nat` with arity 1) as the *predicate* symbol for such a relation

  - if `N` is a variable, atom `nat(N)` represent the proposition "`N` is a natural number"
  - according to our current *interpretation*

e.g. in our interpretation, atom `nat(s(s(z)))` means that 'two is a natural number'

Natural Numbers in Prolog I

A first program

```
nat(z).        % zero is a natural number
nat(s(z)).     % one is a natural number
nat(s(s(z))). % two is a natural number
...
```

- remarks
  - infinite number of clauses (facts) for infinite numbers
  - ! not exactly in the spirit of axiomatic systems
  - in particular, of Peano's one
  - we just used *facts*
  - *rules* are what triggers *intensional representation*, with universal variables
  - *finite* representation for (potentially) *infinite* propositions

Natural Numbers in Prolog II

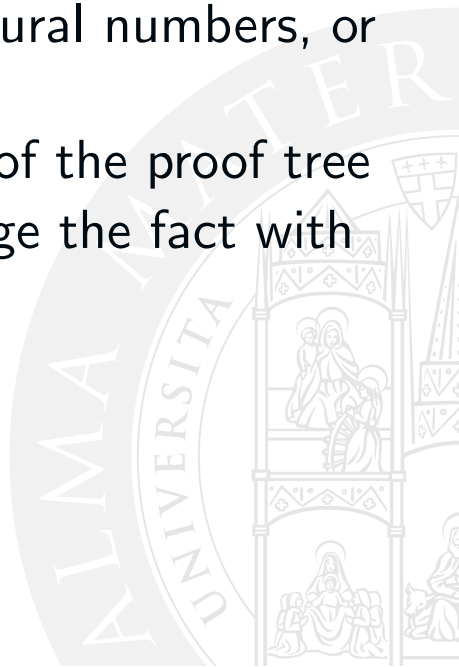
A second program: recursive rules

```
nat(z).                  % zero is a natural number
nat(s(N)) :- nat(N).     % if N is a natural number
                         % its successor is a natural number
```

- remarks
  - one fact and one rule for infinite numbers
  - a *recursive* rule
- goals
  1. `?- nat(z).`
  2. `?- nat(0).`
  3. `?- nat(s(s(s(s(s(s(z))))))).`
  4. `?- nat(N).`
  5. `?- nat(s(N)).`

Natural Numbers in Prolog III

- remarks
  - z is zero, 0 is not zero
  - recursive data structures are powerful and expressive, yet unreadable for humans: which is why Prolog is actually *impure* LP
  - LP allows for *generation* of data—-e.g., the set of natural numbers, or the set of positive numbers
  - *unlimited* number of SLD *refutations*: infinite branch of the proof tree
  - *order of clauses* matters in Prolog: what if we exchange the fact with the rule?

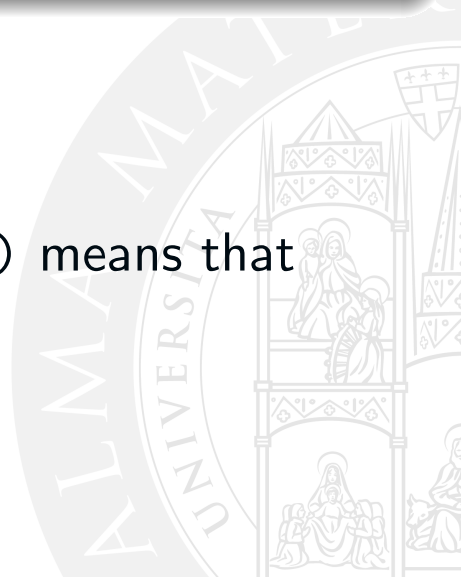


Computing with Naturals in Prolog I

Sum

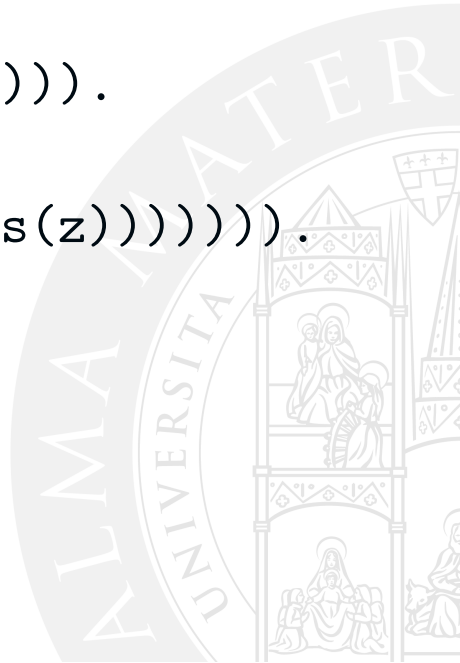
```
plus(z, N, N).          % zero plus N is N
plus(s(M), N, s(P))     % if M plus N is P, then
  :- plus(M, N, P).     % adding N to the successor of M
                        % returns the successor of P
```

- remarks
  - based on the same representation of $\mathbb{N}$ used above
  - `plus/3` actually represents an equation: `plus(X,Y,Z)` means that $X + Y = Z$



Computing with Naturals in Prolog II

- goals
  1. `?- plus(s(z),s(s(z)),S).`
  2. `?- plus(0,s(0),S).`
  3. `?- plus(X,s(s(z)),s(s(s(s(s(s(z)))))).`
  4. `?- plus(s(s(s(s(z)))),Y,s(s(s(s(s(s(z)))))).`
  5. `?- plus(X,Y,s(s(s(s(s(s(z)))))))`
  6. `?- plus(X,s(s(z)),Y), plus(X,Y,s(s(s(s(s(s(z))))))).`



Computing with Naturals in Prolog III

- remarks
  - again, `z` is zero, `0` is not zero
  - no predefined input/output parameters for `plus/3` procedure

  → atoms represent equations
  - generation of possible solutions
  - equations can be combined in systems of equations

Lists in Prolog I

Lists

- list are defined via two constructors
  - nil the empty list, containing no elements
  - cons the constructor *cons*, taking an element H and a list T, and generating the list $cons(H, T)$

e.g. $cons(a, cons(b, cons(c, nil)))$ would represent list a, b, c

- typical *recursive data structures*
- used to represent *sequences* of any sort

Lists in Prolog II

Prolog lists

- in Prolog, list are defined via two analogous constructors
  - `[]` represents the empty list, containing no elements—a *constant*
  - `.` stands for *cons*, taking an element `H` and a list `T`, and generating the list `.(H,T)`—a *functor* of arity 2
- Prolog *sequence notation* simplifies writing lists
  - `.(H,T)` can be written as `[H|T]`
  - `.(H,.(H',T'))` can be written as `[H,H'|T']`
  - there, empty list can be omitted

e.g. `[a,b,c]` would represent list a, b, c in Prolog, where

- `a` is the head of the list
- `[b,c]` is the tail of the list
- $mgu([a, b, c], [H|T]) = \{H/a, T/[b, c]\}$

Computing with Lists I

Recursion

- being recursive data structures, lists are typically handled by recursive rules
- which incidentally is also the *only* way to handle repeated operations over sequences in Prolog, where there is nothing like a *cycle* programming construct

Recursion scheme in Prolog

- since Prolog search strategy is depth-first
- in particular, with clauses used orderly, top-down
- *termination* is handled with a fact, typically coming *before* the recursive rule
- as already seen in the cases of `num/1` and `plus/3` above

Typical Example: member I

member/2

Checking whether the first argument is a term that is a member of the list in the second argument

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

- goals
  1. `?- member(b,[a,b,c])`
  2. `?- member(X,[a,b,c]).`
  3. `?- member(g(X),[f(a),g(b),f(c),g(d)]).`
  4. `?- member(z,[XT]).`—

Typical Example: `member` II

- remarks
  - search strategy: left to right through the list
  - devising out all the members of the list
  - conditional membership—given a certain computed substitution
  - generation of lists

What We do not Do

Many interesting things are left out...

- that are relevant for Prolog programming
  - operator definition
  - conditionals
  - control: cut & fail
  - negation as failure (NAF)
  - closed world assumption (CWA)
  - arithmetic
  - meta programming
- and many more

! however, this is not a Prolog course

- and we already discussed whatever could be useful for our purposes

References I

Apt, K. R. (2005).
The logic programming paradigm and Prolog.
In Mitchell, J. C., editor, *Concepts in Programming Languages*, chapter 15, pages 475–508. Cambridge University Press, Cambridge, UK.

Colmerauer, A. and Roussel, P. (1996).
The birth of Prolog.
In Bergin Jr., T. J. and Gibson Jr., R. G., editors, *History of programming languages—II*, volume II, pages 331–367. ACM, New York, NY, USA.

Console, L., Lamma, E., Mello, P., and Milano, M. (1997).
Programmazione logica e Prolog.
UTET Libreria.

Denti, E., Omicini, A., and Ricci, A. (2001).
tuProlog: A light-weight Prolog for Internet applications and infrastructures.
In Ramakrishnan, I., editor, *Practical Aspects of Declarative Languages*, volume 1990 of *Lecture Notes in Computer Science*, pages 184–198. Springer Berlin Heidelberg.
3rd International Symposium (PADL 2001), Las Vegas, NV, USA, 11–12 March 2001. Proceedings.

References II

Denti, E., Omicini, A., and Ricci, A. (2005).
Multi-paradigm Java-Prolog integration in tuProlog.
Science of Computer Programming, 57(2):217–250.

Nilsson, U. and Maluszynski, J. (1995).
Logic, Programming and Prolog.
John Wiley & Sons, Inc., New York, NY, USA.

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Academic Year 2016/2017