CSC4504/Prolog. : Formal Languages & Applications

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Prolog
/~gibson/Teaching/CSC4504/Problem8-Prolog.pdf
Logic programming with Prolog

We are going to look at logic programming
We choose Prolog as a typical example
• Started around 1970
• Used for many applications:
  relational databases, mathematical logic, abstract problem solving, understanding natural language, design automation, symbolic equation solving, biochemical structure analysis, …
• Most recent use is in AI
Logic programming with Prolog: history

Prolog from research at the University of Aix-Marseille in the late 60's and early 70's.

Alain Colmerauer and Phillipe Roussel (University of Aix-Marseille) collaborated with Robert Kowalski (University of Edinburgh) to create the design of Prolog as we know it today.

• Kowalski - the theoretical framework
• Colmerauer's - formalize the Prolog language.

1972 birthdate of Prolog.

The first Prolog compiler - David Warren, an expert on Artificial Intelligence at the University of Edinburgh – *Warren’s Abstract Machine (1983)*
Logic programming with Prolog: some reading

Predicate Logic as a programming language, Kowalski, 1974

Prolog - The language and its implementation compared with LISP, Warren, Pereira and Pereira, 1977

The Early Years Of Logic Programing, Robert Kowalski, 1988

The birth of Prolog, Colmeraurer and Roussel, 1996
For beginners

Writing a Prolog program is not like specifying an algorithm in the conventional way.

The programmer asks what formal relationships and objects occur in the problem.

Program searches for what relationships are ‘true’ in the desired solution.

Prolog is descriptive (what) rather than prescriptive (how)
Prolog Computation

The way the computer carries out a computation for Prolog is specified partly by:

• the logical declarative semantics of Prolog
• the new facts Prolog can ‘infer’ from the given facts
• explicit control information given in the program
Prolog Overview

Prolog is a practical and efficient implementation of many aspects of ‘intelligent’ program execution like:

- non-determinism,
- parallelism,
- pattern-directed procedure call

Prolog provides a uniform data structure called the term, around which all data and programs are constructed.

A Prolog program consists of a set of clauses, where each clause is either:

- a fact about the given information , or
- a rule about how the solution may relate to or be inferred from the given facts
Introducing Prolog

To start, we look at essential elements of the language in real programs, without becoming diverted by details, formal rules, and exceptions.

We aren’t trying to be complete or precise.

We hope to be writing programs ASAP.

Concentrate on the basics:

• facts,
• questions,
• variables,
• conjunctions,
• rules
Objects and relationships

Prolog is used when we wish the computer to solve problems that can be expressed in the form of objects and their relationships.

Example:

Paul owns the car

This declares that a relationship (ownership) exists between one object (Paul) and another object (the car).

Note:

- the relationship has an order
- the objects are concrete
- we didn’t say ‘Paul owns a car’!!
Abstraction in relationships

Some relationships don’t always mention all the objects that are involved.

Example:

*Paul is intelligent.*

Here, there is a relationship (being intelligent) which involves Paul. We do not say who finds Paul intelligent (or why)

We abstract away from this information as we choose only to say what we want to say.

In Prolog, the amount of detail given has influence on the things you can accomplish.
A bit of philosophy

We are all familiar with rules like:

2 people are sisters if they are both female and have the same parents

This tells us:

• something about what it means to be sisters
• how to find out if 2 people are sisters

Note:

• these rules are usually oversimplified, but acceptable as definitions.
• do not expect a definition to tell us everything about something
Philosophy continued ...

Most people would agree that there is ‘more to being sisters’ in real life than the rule would suggest.

When solving a problem, we must concentrate only on the rules which can help us.

We should consider an imaginary and simplified definition if it is sufficient for our purposes.

Prolog programming consists of:

• declaring \textit{facts} about objects and relationships
• declaring \textit{rules} about objects and relationships
• asking \textit{questions} about objects and relationships
Suppose we told Prolog a rule about sisters. We could ask whether Paul and Peter were sisters. Prolog would search through everything it knows (about sisters, paul and peter) and return yes or no.

**Question:**

if Prolog does not have enough information to decide if Paul and Peter are sisters then what should it do?

**Answer:** this defines part of the boundary between philosophy and logic … we shall see what Prolog actually does (later on)
The syntax of facts

Informally we know that Paul likes Beer.

Formally, in Prolog, we write: `likes(paul, beer).

Note:

• names of objects and relationships must begin with a lower-case
• the relationship is written first
• the objects are separated by commas
• the full stop character ‘.’ must come at the end of a fact
Some example facts

- good(beer).
- drinks(paul, beer).
- buys(paul, beer, peter).
- owes(peter, beer, paul).
- mix(beer, vodka, drunk).

Beer is good
Paul drinks beer
Paul buys beer for Peter
Peter owes Paul beer
Mixing beer and vodka makes you drunk

Note: when using names we must decide how to interpret the name. The programmer decides on the interpretation… so make it consistent and comprehensible.
Some terminology

The names of objects in round brackets are arguments.

The name of the relationship before the round brackets is the predicate.

The names chosen are arbitrary, but we normally select names to correspond to their interpretation.

The order of arguments is also arbitrary, but again we should try to match intuition in a consistent manner.

Relationships can have an arbitrary number of arguments:

    cocktail(paul, favourite, beer, gin, wine, whiskey).

A collection of facts is called a database.
Questions in Prolog

Once we have some facts, we can ask questions about them.

In Prolog, a question looks like a fact, except that we put a special symbol before it … a question mark and hyphen.

?- likes(paul,beer).

When a question is asked, Prolog searches through the database of facts looking for matches.

Two facts match if their predicates are the same and if their arguments are the same.

If a matching fact is found then Prolog responds yes otherwise Prolog responds no
Facts and questions

Consider the following database of facts:

likes(paul,beer).
likes(paul,wine).
canmakeyoudrunk(wine).
canmakeyoudrunk(beer).
canmakeyoudrunk(paul).

Now we pose the following questions:

likes(paul,money)
isUniversity(oxford)

In both cases, the answer is no, even if the intended meaning is true. In prolog no is returned when nothing matches.
Installing SWI Prolog

http://www.swi-prolog.org

### Download SWI-Prolog stable versions

<table>
<thead>
<tr>
<th>Binaries</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>12,243,941 bytes</td>
<td>Self-installing executable for MS-Windows. Installs swipl-win.exe and swipl.exe. Works on Windows XP/Vista/7/8. This binary is linked against GMP 5.0.5, which implies that it is covered by the LGPL-V3 license. See below.</td>
</tr>
<tr>
<td>12,854,205 bytes</td>
<td>Self-installing executable for Microsoft’s XP/Vista/7/8 64-bit editions. See the reference manual for deciding on whether to use the 32- or 64-bits version. This binary is linked against GMP 5.0.5, which implies that it is covered by the LGPL-V3 license. See below.</td>
</tr>
<tr>
<td>20,472,051 bytes</td>
<td>SWI-Prolog 6.6.6 for MacOSX 10.6 (Snow Leopard) and later on Intel Mac OS X disk image with relocatable application bundle. Needs quartz (X11) installed for running the development tools. Currently, version 2.7.5 is required. You can check the version by opening an X11 application and then checking <del>about</del> in the X11 menu. The graphical application is experimental. The bundle also provides the commandline tools in contents/MacOS. The command line tools need at least MacOS 10.6 (Snow Leopard). The graphical application needs at least MacOS 10.7 (Lion).</td>
</tr>
</tbody>
</table>

### Sources

| 14,838,653 bytes | SWI-Prolog source for 6.6.6 |
| 1,910,584 | SWI-Prolog 6.6.6 reference manual in PDF |
Using SWI Prolog
A first experiment: Paul and Andrew share a dad so they are siblings??

1 ?- [user].  Interactive programming- input facts and rules
CTRL RETURN ??
|: sibling(X,Y) :- parent(Z,X), parent(Z,Y).  RULE
ERROR: user://1:10:39: Syntax error: Operator expected
|: sibling(X,Y) :- parent(Z,X), parent(Z,Y).  RULE
|: parent(paul, dad).  FACT
|: parent(andrew, dad).  FACT
|:
|:
% user://1 compiled 0.02 sec, 4 clauses
true.

2 ?- sibling(paul, andrew).  QUERY
false.

Why is this not true?
Watch out for ordering of parameters
A first experiment: Paul and Andrew share a dad so they are siblings???
... let’s get it right

| sibling(X,Y) :- parent(Z,X), parent(Z,Y).
| parent(dad,paul).
| parent(dad,andrew).
|:
% user://1 compiled 0.01 sec, 4 clauses
true.

2 ?- sibling(paul,andrew).
true.

3 ?- sibling(andrew,paul).
true.

4 ?- sibling(X,Y).
X = Y, Y = paul.

5 ?- sibling(X,Y).
X = Y, Y = paul
X = paul,
Y = andrew
X = andrew,
Y = paul
X = Y, Y = andrew.

RETURN finishes the search
; “semi-colon” keeps searching
Write a Prolog program to capture the following properties:

paul is the brother of jill
jill is the sister of andrew
Brothers share a common parent
Sisters share a common parent
Siblings share a common parent

Check whether or not (depending on your program)

paul and andrew are siblings
Built-in predicates

?- write(hello).
hello
true.

?- write(Hello).
_G2137
true.

?- write(hello world).
ERROR: Syntax error: Operator expected
ERROR: write(hello
ERROR: ** here **
ERROR: world).

?- write('hello world').
hello world
true.

?- write("hello world").
true.
History Commands:

!!.  Repeat last query
!nr. Repeat query numbered <nr>
!str. Repeat last query starting with <str>
!?str. Repeat last query holding <str>
^old^new. Substitute <old> into <new> of last query
!nr^old^new. Substitute in query numbered <nr>
!str^old^new. Substitute in query starting with <str>
!?str^old^new. Substitute in query holding <str>

h. Show history list
!h. Show this list
History Commands Examples:

17  ?- h.
   1   [user].
   2   sibling(paul,andrew).
   3   sibling(andrew,paul).
   4   sibling(X,Y).
   5   sibling(X,Y).
   6   sibling(X,Y).
   7   sibling(X,Y).
   8   sibling(X,Y).
   9   write(hello).
  10  write(Hello).
  11  ?- write('hello world').
  12  write('hello world').
  13  write("hello world").
  14  write("hello world").
  15  write('hello world').
  16  sibling(X,Y).

18  ?- !10.
   write(Hello).
   _G3436
   true.

19  ?- !sibling.
   sibling(X,Y).
   X = Y, Y = paul.

Terminate the interaction with halt.
Loading an existing prolog database (prolog-example1.pl)

% /Users/jpaulgibson/Documents/MyPrograms/MyProlog/prolog-example1.pl

/**
 * A simple first example
 *
 ***/

likes(paul,beer).
likes(paul,whiskey).
likes(andrew,beer).
likes(andrew,wine).
Loading an existing prolog database

1 ?- consult('/Users/jpaulgibson/Documents/MyPrograms/MyProlog/prolog-example1.pl').
   % /Users/jpaulgibson/Documents/MyPrograms/MyProlog/prolog-example1.pl compiled 0.00 sec, 5 clauses
   true.

2 ?- likes(X,Y).
   X = paul,
   Y = beer
   X = paul,
   Y = whiskey
   X = andrew,
   Y = beer
   X = andrew,
   Y = wine.

3 ?-

Note: to load a file into the interpreter we can also write:
['/Users/jpaulgibson/Documents/MyPrograms/MyProlog/prolog-example1.pl'].
Prolog has built-in lists

% /Users/jpaulgibson/Documents/MyPrograms/MyProlog/list-append.pl

/**
* A simple list append example
*
**/

append([],List,List).
append([H|Tail],X,[H|NewTail]) :- append(Tail,X,NewTail).

['/Users/jpaulgibson/Documents/MyPrograms/MyProlog/list-append.pl'].
% /Users/jpaulgibson/Documents/MyPrograms/MyProlog/list-append.pl compiled 0.00 sec, 3 clauses
true.

?- append([a,b,c],[d,e],X).
X = [a, b, c, d, e].

Question: how does this work?
Prolog has built-in lists

List unification

[X|Y] unifies with [a,b,c] with the unifier \{X = a, Y = [b,c]\}.

[X|Y] unifies with [a,b,c,d] with the unifier \{X = a, Y = [b,c,d]\}.

[X|Y] unifies with [a] with the unifier \{X = a, Y = []\}.

[X|Y] does not unify with [].
Prolog has built-in lists

### List unification

<table>
<thead>
<tr>
<th>Query</th>
<th>Unifier</th>
<th>Prolog answer</th>
</tr>
</thead>
</table>
| `?- append([], [b, c, d], [b, c, d]).` | `{List = [b, c, d],
X = [b, c, d]}` | yes           |
| `?- append([], [b, c, d], X).`       | `{List = [b, c, d],
X = [b, c, d]}` | X = [b, c, d] |
| `?- append(X, Y, Z).`             | `{X = [],
Y = List,
Z = List}`        | X = [], Y = Z  |
| `?- append([], [b, c], [b, c, d]).` | None                           | no            |
Prolog has built-in lists

List unification

1 Call  append([a,b,c],[d,e],Result).
2 Call  append([b,c],[d,e],NewTail).
3 Call  append([c],[d,e],NewTail1).
4 Call  append([], [d,e], NewTail2).
5 exit  NewTail2 = [d,e]
6 exit  NewTail1 = [c,d,e]
7 exit  NewTail = [b,c,d,e]
8 exit  Result = [a,b,c,d,e]

%%% Initial call
%%% Result = [a|NewTail]
%%% First recursive call
%%% NewTail = [b|NewTail1]
%%% Second recursive call
%%% NewTail1 = [c|NewTail2]
%%% Third recursive call
%%% Unifying with base case
%%% of append.
%%% Back substitution of
%%% NewTail2
%%% Back substitution of
%%% NewTail1
%%% Back substitution of
%%% NewTail
Prolog has built-in lists

List unification - we can see this with the trace functionality

?- trace.
true.

[trace] 8 ?- append([a,b,c],[d,e],X).

Call: (6) append([a, b, c], [d, e], _G3547) ? creep
Call: (7) append([b, c], [d, e], _G3629) ? creep
Call: (8) append([c], [d, e], _G3632) ? creep
Call: (9) append([], [d, e], _G3635) ? creep
Exit: (9) append([], [d, e], [d, e]) ? creep
Exit: (8) append([c], [d, e], [c, d, e]) ? creep
Exit: (7) append([b, c], [d, e], [b, c, d, e]) ? creep
Exit: (6) append([a, b, c], [d, e], [a, b, c, d, e]) ? creep
X = [a, b, c, d, e].

?- notrace. trace off
List membership

member (X, [X, Xs]).   % member 1
member (X, [Y|Ys]) :- member(X,Ys) % member 2

member1 says that X is in the list if it is the first thing in the list
member2 says that X is in the list if it is in the tail of the list

?- member(1, [1,2,3]).
  Yes
?- member(5,[1,2,3]).
  No
?- member (X, [1,2,3]).
  X = 1?;
  X = 2?;
  X = 3?;
  no
Prolog has built-in lists

**PROBLEM**: write a Prolog program for reversing a list

1 ?- ['/Users/jpaulgibson/Documents/MyPrograms/MyProlog/list-reverse.pl'].
% /Users/jpaulgibson/Documents/MyPrograms/MyProlog/list-reverse.pl compiled 0.00 sec, 3 clauses
true.

2 ?- reverse([1,2,3], X).
X = [3, 2, 1].
How do queries (with variables) execute?

To begin, all we can get back from our database of facts is the information that we have put in.

It would be more interesting to ask things like:

* what does paul like?*
* what can make you drunk?*

In Prolog, this is what we use variables for … these are names (starting with capital letters) which stand for objects to be determined by Prolog. A variable can be:

- *instantiated* … when there is an object that it stands for, or
- *not instantiated* … when what it stands for is not yet known
Questions with variables

When faced with a question such as:

*what does Paul like?*

Prolog will search through all its facts to find a match.

?-likes(paul,X).

X = beer.

Prolog will then wait for further instructions.

**Question:** why beer and not wine?

**Question:** why not both?
How it searches

• When the question is asked, the variable X is not instantiated

• Prolog searches for a fact where:
  • the predicate is likes
  • the first argument is paul

• Once a match is found, it instantiates X as the 2nd parameter

• Prolog searches in top-down order in the file (on the page)

• So, likes(paul, beer) is found first and so X is set to beer.

• Note: Prolog now marks the place where this match was found … this is important later.
What to do once a match is made

There are 2 logical choices as to how to continue:

• If you are satisfied with one answer you type **RETURN**
• If you want to search for more matches then type ; RETURN

If you continue your search then:

• Prolog forgets that it has instantiated X to beer
• Continues the search at the point at which it previously found a match (the place marker)
• If it finds a match then you can again choose to continue as before

Finishing the search:

Prolog returns **no** when no more matches are found after the current place marker. When this occurs you can try another question or give more facts
Conjunctions

We may wish to structure our questions:

*does paul like beer and wine?*

and is the logical conjunction … represented in Prolog by a comma

```
?- likes(paul,beer), likes(paul,wine).
```

We can now ask more interesting questions.

**Question:** how can we find something that paul likes and which can make you drunk?
Paul likes (some)thing(s) that can make him drunk?

If we type in the following question:
?- likes(paul,X), makesyoudrunk(X).

Prolog will reply

X=beer

How does this work?

Prolog attempts to satisfy the first goal … and marks the place in the database where it finds the first matching fact. It then attempts to satisfy the second goal (using the previous instantiation) and marks the first matching place in the database.

Note: we have not shown that *Paul likes all things that can make you drunk* … even though this is true in the database and false in the real world.
Backtracking: an introduction

The previous example illustrated a very simple case where:

the initial values that variables are instantiated to do not change at later points in the search.

**Question:** can you think of an example set of facts, and a question which could not be matched in this way … even though a match could be found if we could *go back and re-instantiate* a variable to a different value?

**Note:** this technique is known as backtracking and is fundamental to programming in Prolog.
Backtracking: an example

likes(paul, beer).  
likes(paul, wine).  
likes(paul, football).  
hates(patricia, football).  
hates(patricia, motorracing).

?- likes(paul, X), hates(patricia, X).

Prolog execution:
match1 X = beer
marker1 = 1
nomatch2
restart 2
match X = wine
marker1 = 3
nomatch 2
restart 4
match X = football
marker 1 = 4
match2
marker2 = 2
X = football

Finding another match ---

Type ;RETURN and Prolog re-starts the search at the current markers.
Rules: more complex reasoning

We wish to express the following:

Paul likes everything that can make you drunk
Peter likes only those things that can make you drunk

We do this using rules:

\[
\text{makeyoudrunk}(X) \leftarrow \text{likes}(paul,X).
\]
\[
\text{likes}(peter,X) \leftarrow \text{makeyoudrunk}(X)
\]

Terminology:

- \text{likes}(peter,X) is called the \textit{head} of the rule (2)
- \text{likes}(paul,X) is called the \textit{body} of the rule (1)
- \textit{h:-b} can be interpreted as ‘\textit{h if b}’
Some More Terminology

A *clause* (of a predicate) is any fact or rule (which includes this predicate).

For example,

- `likes(paul, beer)`.
- `makesyoudrunk(X) :- likes(paul, X)`.
- `likes(paul, X) :- makesyoudrunk(X), cheap(X)`.

are all *clauses* of the predicate `likes`

**Note:** when trying to answer a question, Prolog may not use, or need to use, all the clauses.
Some Unexpected Reasoning

/*1*/ drinker(paul).
/*2*/ likes(patricia, wine).
/*3*/ likes(patricia, chocolate).
/*4*/ likes(paul,X) :- likes(X,wine).
/*5*/ drinks(paul,X) :- likes(paul,X).

Question (1):
?- drinks(paul,X).
results in what response?

Question (2):
which clause is not relevant to question (1)
Recursive Rules

Imagine that we wish to examine the ancestry between certain people.

We have a list of parenthood facts. For example:

parent(tom,paul).

parent(paul, andrew).

parent(bill, tom).

Here, we should be able to see that bill is paul’s grandparent because bill is tom’s parent and tom is paul’s parent. We can thus write a grandparent rule:

grandparent(X,Y) :- parent (X,Z), parent(Z,Y).
Recursive rules continued ...

parent(tom, paul).

parent(paul, andrew).

parent(bill, tom).

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

We can now deduce:

grandparent(bill, paul).

grandparent(tom, andrew).

But, how do we note that andrew is an ancestor of tom?

Answer: why not just write a greatgrandparent rule?
Great grandparent rule

ggp(X,Y) = grandparent(X,Z), parent(Z,Y).

Now, to define ancestry we just have to say that if A is:

• a parent
• a grandparent, or
• a greatgrandparent, or …

of B then

A is an ancestor of B

Question: can you write this rule in prolog?

Question: this will work to show that bill is an ancestor of andrew, but why is it not a good approach to ancestry?
Ancestry by Recursive Rules

Without recursion we have to keep on adding rules for being an ancestor indefinitely.

A better way is to define ancestor in terms of itself:

A is an ancestor of B if A is B’s parent or if A is an ancestor of B’s parent.

**Question:** can you write this in prolog

**Hint:** it requires 2 rules …

- a non-recursive base case
- a recursive case
Prolog Ancestry

\[
\text{ancestor}(X,Y) :\text{ parent}(X,Y).
\]

\[
\text{ancestor} (X,Y) :\text{ parent}(X,Z), \text{ ancestor} (Z,Y).
\]

Now, if we query or database:

\[
\text{parent}(\text{tom}, \text{paul}).
\]

\[
\text{parent}(\text{paul}, \text{andrew}).
\]

\[
\text{parent}(\text{bill}, \text{tom}).
\]

With

\[
?\text{- ancestor(bill,andrew)}.
\]

Prolog will reply

\[
\text{yes}.
\]

**Question:** can you follow the prolog process to see how this answer is achieved?
Recursive Rules and ordering

We originally gave the rules in the following order:

\[
\text{ancestor}(X,Y) :- \text{parent}(X,Y).
\]
\[
\text{ancestor}(X,Y) :- \text{parent}(X,Z), \text{ancestor}(Z,Y).
\]

In Prolog, the order of the rules is often very important with regard to the processing of queries.

**Question:**

In this case, would it matter if we had reversed the ordering?
Anonymous Variables in Rules

Suppose that we are interested in whether paul is a murderer, but we are not interested in who he has murdered.

We have a database of facts, including:

\[
murdered(john, paul).
murdered(paul, john).
murdered(paul, beer).
\]

We could type the query: \texttt{?- murdered(paul,X)} to see if paul is a murderer but it is better to define a new rule with an anonymous variable:

\[
murderer(X) :- murdered(X, _)
\]
Multiple Anonymous Variables

We can have >1 anonymous variable in a clause. For example:

? - parent(_,_)  

This is asking if there are any parent relationships in the database

Note: each of the “_” means a different logical variable. So, this query is equivalent to parent(X,Y) and not parent(X,X)
Arithmetic Computation in Prolog

• Prolog: designed for *symbolic* rather than *numeric* computation
• Not good for numeric problems
• Imperative languages are good at numeric but terrible at symbolic
• Functional languages are good at both.

• Prolog provides a bare minimum:
  • +
  • -
  • *
  • /
  • div  --- *Integer* division
  • mod  --- *Integer* remainder
Operators do no behave exactly as expected:

?- 3 +4.

no

?- 

So far as Prolog is concerned, “3+4” is an expression corresponding to a structure (see later). A structure cannot be proved from a database and so the response is ‘no’.

We must tell Prolog to treat the structure as an arithmetic expression and actually evaluate it. We could try:

?- X = 3+4.

X = 3+4?

yes

The ‘=’ operator simply means ‘do these 2 terms match’. Prolog says they match if X is the term “3+4” … (not very useful!)
Comparison and assignment

Do not confuse Prolog’s ‘=‘ with Java’s ‘==’. They are very different. Prolog’s is the matching operator (a bit like ‘= =‘ in JAVA … see later)

We must use the ‘assignment’ operator ‘is’:

?- X is 3 +4.

X = 7?

yes

The ‘is’ is only superficially like ‘==‘ in JAVA.

There must be a logical variable on the left hand side and an arithmetic expression on the right hand side. The ‘is’ tells Prolog to evaluate the RHS and match the result with the variable on the left.

We can have more complex expressions:

?- X is 1+2*3/4-5

X = -2.5?

no
More Complex Expressions

We can have expressions containing other logical variables:

?- X is 3 + 4, Y is X + X.

Y = 14

X = 7 ?

yes

Note: the order of the sub-goals is important:

?- Y is X + X, X is 3 + 4.

{INSTANTIATION ERROR: _36 is _34+_34 - arg2}

Here, sub-goals are evaluated from left to right and because X has not yet been instantiated, the query cannot be evaluated

‘_34’ and ‘_36’ are the internal names that Prolog gives to variables X and Y !!!!
What is is?

For ‘is’ to work, all the logical variables in the expression on the right hand side must be instantiated.

We can’t use ‘is’ backwards --- ‘is’ is functional not relational

This only works one way: for efficiency purposes.

Conceptually, there is no reason why ‘is’ shouldn’t be able to work backwards: but it would be very inefficient …

Question: can you see why?

Example (not real Prolog) of what would be nice:

?- 64 is X * Y
Y=64
X=1?;
Y = 32
X = 2?; ...
Other arithmetic operators

The usual arithmetic comparison operators are also available:

\[
\text{=:=} \quad \text{Equal} \\
\text{\textbackslash =} \quad \text{Not equal} \\
<, >, >=, =< \quad \text{greater/less…}
\]

As with ‘is’, these will not work if there are uninstantiated logical variables in the expressions being compared.

Usually Prolog programmers do not use ‘=:=‘ and ‘\textbackslash =\textbackslash =‘. Instead, the general matching and non-matching operators ‘=‘ and ‘\textbackslash =‘ are used.
Is is not assignment

Despite the superficial similarity, the ‘is’ operator is not an assignment:

?- 64 is 32 * 2. % 1
yes
?- X is 64, X is 32 * 2. %2
X = 64?
yes
?- X is 64, X is 1+2. %3
no

%1 -- 64 matches the result of 32*2
%2 -- The first subgoal succeeds, instantiating X to 64. The expression in the second subgoal evaluates to 64 and since the values on either side of the ‘is’ can be matched, yes is returned
%3 -- 1st subgoal succeeds, in second subgoal the expressions cannot be matched and so Prolog returns no.
Is is still not assignment

?- X is X+1. %4  
{INSTANTIATION ERRPR: _36 is _33+1 -arg 2}  
?- X is 64, X is X +1. %5  
no

%4 -- The system cannot evaluate the RHS ‘X+1’ because X has not been instantiated, and so the query fails  
%5 -- The 1st subgoal succeeds and instantiates X to 64. X+1, on the RHS of the 2nd subgoal is evaluated to 65. 64 and 65 cannot be matched across the ‘is’ and so the result is no
Some complex queries and data structures

course(pl2, se109, gibson, paul, ‘pgibson@cs.may.ie’, salesian, 117, Tuesday, 10, callan, slt).

To find out when I lecture I write the query:

?- course(_, _, gibson, paul, _, _, _, Day, Hour, _).

Hour = 11
Day = tuesday

To find out what and where I am lecturing I could use the following query:

?- course(Name, _, gibson, paul, _, _, _, _, Building, Room).
Room = slt
Building = callan
Name = pl2
Without structures

• This is very clumsy
• The course has 12 arguments
• Must remember the order of arguments (no type checking to help)
• Which room is lecturer’s office and which is lecture theatre
• Things would be better if we could group related data. For example:
  
course(Description, Lecturer, Time, Room).

  requires only 4 arguments and can be done using Prolog structures
• For example:
  
  • the data about the course description could be written as description(pl2, se109).
  • the data for a Room as room(callan, slt).
  • the data for Time as time(Tuesday 10).
The new structured data base entry

course( description(pl2,se109),
    lecturer(gibson, paul, ‘pgibson@cs.may.ie’, room(salesian, 117)),
    time(tuesday,10),
    room(callan,slt) ).

Note: the use of the same room structure for offices and lecture theatres

Advantages: program easier to understand, queries easier to write, eg:

?- course(_lecturer(gibson,paul,_,_), Time, _).

Time = time (Tuesday,10)

Disadvantages: it is longer
Structured Queries

We can now use the course structure to define a new relation. For example, to test if a room is occupied at a given time:

\[
\text{occupied}(\text{Room}, \text{Time}) \leftarrow \text{course}(\_, \_, \text{Time}, \text{Room}).
\]

Now we can write a query:

?- occupied(room(callan,slt), time(tuesday,10)).

yes

Or another to find out when a room is occupied:

?- occupied(room(callan,slt), Time).

Time = time(tuesday,10)?

Or another to find what room is occupied at a given time:

?- occupied(Room, time(tuesday,10)).

Room = room(callan,slt)?
Structure Syntax

functor “(“ ___ term “)” ___

“,”

Or, in EBNF:

\[
\text{structure} = \text{functor} \text{ “(“ \text{term} \{\text{“,” \text{term}} \text{“)“}}
\]

**Functor**: the name of the ‘class’ of structured object. They have the same syntax as alphanumeric atoms.

**Term**: Any Prolog data object (including structured objects) … the terms are called the components of the structure

**Note**: 2 structures with the same functor do not have to have the same (number of) components … Prolog has no type checking
Structure classes and types

The ‘type’ of a structured object is defined by:

• its functor name
• its arity -- number of components

Thus, f(a,b,c) and f(a,b,c,d) are objects of the same ‘class’ but of different ‘type’ within the ‘class’.

Now, we can have many different types in the same class:

```
student(fred,123,taught,pl2,55)
student(paul,research)
```

Note: the absence of type checking could lead to problems. For example, having a research student on a taught course:

```
student(paul,123,research,pl2,65)
```
Processing such structures

Assuming that we don’t make typing errors, processing these ‘variant records’ (the term is common in imperative languages) is simple:

\[
pass(\text{Name}, _, _, \text{Mark}) : - \text{Mark} \geq 60.
\]

Now we can test if paul and fred have passed their exams:

?- pass(student(fed,123,taught,pl2,65)).

yes

?- pass(student(paul,research)).

no

This last query fails because the structure has a different number of arguments to that to which we are trying to match.

Note: if we make a mistake the system may not notice:

?- pass(student(drinks,lots,of,beer,80)).

yes

Functional languages give all the flexibility of structures plus safe type checking
Simple Input/Output

Write predicate

write( ) Writes a single term to the terminal.

write_ln() Writes a term to the terminal followed by a new line.

tab(X) Writes an X number of spaces to the terminal.
Simple Input/Output

**Read** predicate

- `read(X)` Reads a term from the keyboard and instantiates variable `X` to the value of the read term.
- This term to be read has to be followed by a dot “.” and a white space character (such as an enter or space).
- For example:
  
  ```prolog
  hello :-
  write('What is your name ?'),
  read(X),
  write('Hello'), tab(1), write(X).
  ```
Assertions

- **assert(X)**: Adds a new fact or clause to the database. Term is asserted as the last fact or clause with the same key predicate.

- **asserta(X)**: Same as assert, but adds a clause at the beginning of the database. Exactly the same as **assert(X)**

For example:

```prolog
:- dynamic good/2.
:- dynamic bad/2.
assert(good(skywalker, luke)).
assert(good(solo, han)).
assert(bad(vader, darth)).
```
Retractions

- retract(X)  Removes fact or clause X from the database.
- retractall(X)  Removes all facts or clauses from the database for which the head unifies with X.

For example:
retract(bad(vader, darth)).
retractall(good(_, _)).
?- good(X, Y).
No
What does the following Program program do:

\[
\text{max}(X, Y, Y) :\text{-} X \leq Y.
\]
\[
\text{max}(X, Y, X) :\text{-} X > Y.
\]

?- \text{max}(2, 3, \text{Max}).

\text{Max} = 3
\text{yes}

?- \text{max}(2, 1, \text{Max}).

\text{Max} = 2
\text{yes}

Why is it considered to be inefficient?
Cuts

What happens if at some stage backtracking is forced?

The program will try to re-satisfy max(3,4,Y) using the second clause. This is completely pointless: the maximum of 3 and 4 is always 4. There is no second solution to find.

In other words, the two clauses (X=<Y and X>Y) in the above program are mutually exclusive: if the first succeeds, the second must fail and vice versa.

So attempting to re-satisfy this clause is a complete waste of time. We use a cut to stop this from happening.
Cuts - using ,!.

Here is a more efficient version:

max(X,Y,Y) :- X =< Y, !.
max(X,Y,X) :- X > Y.

?- max(2,3,Max).
Max = 3
yes

?- max(2,1,Max).
Max = 2
yes

Notice the cut

Note that this cut does not change the meaning of the program. Our new code gives exactly the same answers as the old one, but it’s more efficient. In fact, the program is exactly the same as the previous version, except for the cut, and this is a pretty good sign that the cut is a sensible one. Cuts like this, which don’t change the meaning of a program, have a special name: they’re called **green** cuts.
Cuts - using ,!.

Question is this a green cut?
Is it still a correct implementation of max

max(X,Y,Y) :- X =< Y,!.
max(X,Y,X).
Cuts - using ,!.

Question is this a green cut?
Is it still a correct implementation of max

\[
\text{max}(X,Y,Z) :\neg X \leq Y,!, Y = Z. \\
\text{max}(X,Y,X).
\]

Non-green (ie Red) cuts should be used only when absolutely necessary, and it’s a good idea to explicitly comment on any red cuts in your code.
Negation and cuts

Negation in Prolog is implemented based on the use of cut. Actually, negation in Prolog is the so-called *negation as failure*, which means that to negate \( p \) one tries to prove \( p \) (just executing it), and if \( p \) is proved, then its negation, \( \text{not}(p) \), fails. Conversely, if \( p \) fails during execution, then \( \text{not}(p) \) will succeed. The implementation of \( \text{not}/1 \) is as follows:

\[
\text{not(Goal)} :\!- \text{call(Goal)}, !, \text{fail}.
\text{not(Goal)}.
\]

(\text{fail}/0 is a builtin predicate which always fails. It can be trivially defined as \text{fail}:- \ a = b.)
Negation and cuts: difficult for beginners

unmarried_student(X):-
    not(married(X)), student(X).

student(joe).
marrried(john).

?- unmarried_student(joe).
yes
?- unmarried_student(john).
no

But, for logical consistence, asking for unmarried students should return joe as answer, and this is not what happens.

?- unmarried_student(X).
no

The reason for this is that the call to not(married(X)) is not returning the students which are not married: it is just for there is at least a married student.
Prolog Programming Problem

Check if there is a path between two nodes in a directed graph