Programming Paradigms
Unit 6 — Prolog Basics

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Outline

1 Basics of Prolog

2 Backtracking

3 Rules
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1 Basics of Prolog

2 Backtracking

3 Rules
**Logic Programming**

- **Logic programming** is a programming paradigm based on formal logic.
- Programming languages for logic programming are **very different** to those encountered so far.
- They are **declarative** languages.
  - Programmer defines “**what**” to do, program will figure out “**how**” to do it.
  - In other words, you express the logic of a computation without describing its control flow.
  - In imperative and object-oriented languages, the programmer has to do both.
- A program written in a logic programming language is a **set of sentences in logical form**, expressing facts and rules about some problem domain.
One of the most well-known logic programming languages is **Prolog**

- Stands for **PROgramming in LOGic**
- Developed by Alain Colmerauer and colleagues in Marseille in the early 1970s

Prolog is very useful in some problem areas
- such as artificial intelligence, natural language processing, databases, ... 

But pretty useless in others
- such as for instance graphics or numerical algorithms

Major logic programming language families include Prolog, Answer set programming (ASP) and Datalog.
Hello World!

- Start a Prolog interpreter, e.g., gprolog for GNU Prolog or swipl for SWI Prolog
- The Prolog Interpreter shows a prompt and is ready to accept programs
  ?- Let's have a look at a very simple program: Hello World!
  ?- write('Hello World!'), nl.

  This will output (may also say yes instead of true):
  Hello World!
  true

- Although this works, it’s a very untypical example of a Prolog program
Prolog has two parts
- One to represent the data
- Another to query the data

Data is represented in the form of facts and logical rules
- Facts: a fact is a basic assertion about some world
  - Mary is a student
  - Students like books
- Rules: a rule is an inference about facts in that world
  - A person likes books if she/he is a student

Query: a query is a question about that world
- Does Mary like books?
Knowledge Base

- Facts and rules go into a **knowledge base**
  - Prolog allows you to express the contents of a knowledge base
  - Usually a compiler turns this base into a form efficient for querying
- Querying links together facts and rules to tell you something about the world modeled in the knowledge base
Facts

- Facts are basic assertions/statements about objects in the world.

Consider the animation series “Wallace and Gromit”
- Wallace is a good, eccentric cheese loving inventor
- Gromit is a silent yet intelligent anthropomorphic dog
- ...

This is represented in a little Prolog knowledge base of five facts:

- `likes(wallace, toast).`
- `likes(wallace, cheese).`
- `likes(gromit, cheese).`
- `likes(gromit, cake).`
- `likes(wendolene, sheep).`

The facts can be read as the following assertions about the world:
- “Wallace likes toast”
- “Wallace likes cheese”
- ...
Atoms

- **Atoms** refer to individual things/objects
  - e.g., wallace, gromit, wendolene, toast, cheese, cake, and sheep in the facts on the previous slide are atoms

- Atoms always
  - begin with a lower-case character, e.g., wallace
  - or they have to be quoted, e.g., 'Wallace'

- An atom is a **fixed value**, similar to a Ruby symbol
Predicates

- Predicates represent relationships between objects in the world.
- In the facts on the previous example, likes is a predicate.
  - e.g., likes(gromit, cheese)
- The predicate likes has two parameters.
- The order of the parameters is important.
Compiling/Loading the Knowledge Base

- We write the facts in a file "wallace.pl" and load it into the interpreter
  - Checks for syntax errors
  - Compiles the knowledge base into form that is efficient for querying

?- [’wallace.pl’]
% wallace.pl compiled 0.00 sec, 8 clauses
true.

- Now we are ready to ask some questions
- The most basic ones are questions about facts
Queries

- After compilation we can **query** the Prolog knowledge base.

- Prolog tries to **match** a query to known facts.

  ```prolog
  ?- likes(gromit, cheese).
  true
  
  ?- likes(wallace, sheep).
  false
  ```

- This confirms that gromit likes cheese, but wallace doesn’t like sheep.
  - **true** means that Prolog is able to prove this statement given the actual knowledge base.
  - **false** means that Prolog cannot prove this statement given the actual knowledge base.

Knowledge base:

```prolog
likes(wallace, toast).
likes(wallace, cheese).
likes(gromit, cheese).
likes(gromit, cake).
likes(wendolene, sheep).
```
Variables and Instantiation/1

- **Variables** make queries more exciting
  - Variables begin with an uppercase letter or with an underscore '_x_'
- We can ask Prolog to **find values for variables**
  - e.g., Who likes cheese?

?- likes(Who, cheese).

- **Who** is an **uninstantiated** variable, i.e., it has no assigned value
- Prolog searches the KB from the beginning, trying to find a matching fact
- The first matching fact is `likes(wallace, cheese)`, so **Who** is **instantiated** with **wallace**

?- likes(Who, cheese).
Who = wallace

- At this point Prolog outputs **Who = wallace** and asks what to do next
Basics of Prolog

Variables and Instantiation/2

- We can
  - stop searching by just hitting the return key
  - or continue searching by entering ";;"

- If we continue, Prolog
  - forgets the value wallace for the variable Who
  - and continues at the position it previously stopped (using a placemarker)

- Continuing will output Who = gromit; then the query terminates as there will be no further solutions

?- likes(Who,cheese).
Who = wallace ;
Who = gromit.
?-
Anonymous Variables

- Sometimes we want to use a variable but don’t care about its value
  - We don’t want to use the variable anywhere else
- e.g., is there anyone who likes cheese (but we don’t need to know who)

```prolog
?- likes(_,cheese).
true ?
yes
```

- We use an underscore `_` for the anonymous variable
- Several occurrence of `_` in the same clause do not need to be given consistent interpretations
Outline

1 Basics of Prolog

2 Backtracking

3 Rules
By submitting a query, we ask Prolog to try to satisfy a goal.

We can ask Prolog to satisfy the conjunction of two goals using the ""," operator (pronounced "and")

?- likes(wallace,toast), likes(gromit,toast).
no

We can combine conjunctions with variables to make queries more interesting.
Now that we found out that at least one of them does not like toast ... 
... is there something both of them like?

?- likes(wallace,What), likes(gromit,What).
What = cheese;
no

How does Prolog process this query (conceptually)?
It uses backtracking to try to satisfy the first goal and then the second goal.
Process the following query consisting of two goals

?- likes(wallace,What), likes(gromit,What).

first goal          second goal
likes(wallace,toast)
likes(wallace,cheese)
likes(gromit,cheese)
likes(gromit,cake)
likes(wendolene,sheep)

Attempt to satisfy the first goal
The first goal succeeds, instantiating What = toast

Next, attempt to satisfy the second goal
Backtracking/3

?- likes(wallace,What), likes(gromit,What).

The (fully instantiated) second goal likes(gromit,toast) fails

Next, **backtracking** starts: forget the instantiation What = toast and attempt to re-satisfy the first goal
The first goal succeeds again, instantiating \texttt{What = cheese}

Next attempt to satisfy the second goal
The second goal succeeds
Prolog notifies you of success with \texttt{What = cheese} and waits for a reply
Outline

1 Basics of Prolog
2 Backtracking
3 Rules
Suppose we want to state that *Wallace likes all people*

Could be done by many facts

likes(wallace, gromit).
likes(wallace, tom).
...

... but this becomes tedious and long

Another way to state the same would be:

*Wallace likes any object provided it is a person*

This fact is in the form of a more compact *rule*
A rule is a general statement about objects and their relationships.

A rule for being a sister of someone in plain English could be:

\[ X \text{ is a sister of } Y \text{ if:} \]
\[ \begin{align*}
X \text{ is female and} \\
X \text{ and } Y \text{ have the same parents.}
\end{align*} \]

Important: a variable stands for the same object wherever it occurs in a rule.
Rules in Prolog consist of a **head** and a **body** connected by the symbol " :- " (pronounced *if*)

\[ \text{head} :- \text{body} \]

- The head is a predicate that describes what the rule is intended to define
- The body is a conjunction of goals that must be satisfied for the head to be true
- In other words: to prove the head, the body needs to be proven
If we want to express that *Wallace is a friend of anyone who likes cheese*, we could formulate it like this:

```prolog
friend(wallace,X) :- likes(X,cheese).
```

- X is a variable and can match any object.
Prolog tries to satisfy the goal by matching it with rules and/or facts in the knowledge base.

?- friend(wallace,X).

friend(wallace,X) :- likes(X,cheese).
likes(wallace,toast).
likes(wallace,cheese).
likes(gromit,cheese).
likes(gromit,cake).
likes(wendolene,sheep).

After matching the head of the rule, the body of the rule needs to be proven.
Matching Rules/2

Prove the body of the rule

?- likes(X,cheese).

wallace

friend(wallace,X) :- likes(X,cheese).
likes(wallace,toast).
likes(wallace,cheese).
likes(gromit,cheese).
likes(gromit,cake).
likes(wendolene,sheep).

The body of the rule is proven with X = wallace, so the head is proven, too, i.e., Wallace is a friend of Wallace

Backtracking produces the second result, i.e., X = gromit.
Running the query `friend(wallace,X)` will produce two results:
- gromit is ok
- wallace not really ok

We can exclude wallace by saying that `X` shouldn’t be wallace

```
friend(wallace,X) :-
    likes(X,cheese),
    \+(X=wallace).
```

- `\+` is the negation/logical not of a subgoal (`not` can also be used)
- This only lists friends of wallace (those persons who like cheese)
A generalization of the rule on the previous slides would be: 

\[\text{if } X \text{ and } Y \text{ like the same thing } Z, \text{ and } X \text{ and } Y \text{ are different, then } X \text{ and } Y \text{ are friends}\]

This makes our knowledge base more interesting

\begin{verbatim}
likes(wallace, toast).
likes(wallace, cheese).
likes(gromit, cheese).
likes(gromit, cake).
likes(wendolene, sheep).

friend(X,Y) :-
    likes(X,Z),
    likes(Y,Z),
    \+(X=Y).
\end{verbatim}
Let’s try it out with constants in the query

?- friend(gromit,wallace).
yes
?- friend(wallace,gromit).
yes
?- friend(wallace,wallace).
no
?- friend(wallace,wendolene).
no
We can also use variables instead of atoms in the query.

Now let's ask who is a friend of Wallace:

?- friend(wallace,Who).
Who = gromit ? ;
no

Or let's find all pairs of friends:

?- friend(Who1,Who2).
Who1 = wallace
Who2 = gromit ? ;
Who1 = gromit
Who2 = wallace ? ;
no
Queen Victoria’s Family/1

- Just using facts, rules, and variables we can already do some interesting things, e.g., model Queen Victoria’s family
- We use the predicate `parents(X,Y,Z)` to represent *the parents of X are Y and Z*
- We also use `male(X)` and `female(X)` in the obvious way

```prolog
male(albert).
male(edward).

female(alice).
female(victoria).

parents(edward, victoria, albert).
pARENTS(alice, victoria, albert).
```
Now we add a rule for sister: *X is a sister of Y if X is female and they both have the same parents*

```
sister_of(X, Y) :-
    female(X),
    parents(X, M, F),
    parents(Y, M, F).
```

Now you can query:

```
?- sister_of(alice, edward).
true

?- sister_of(alice, X).
X = edward
```
Map Coloring/1

- A slightly more complex example
- Assume we want to color a map, such that two regions with a common border don’t have the same color
Map Coloring/2

- In order to simplify things, we’ll only look at regions 3, 4, 5, and 6 and use the colors red, green, and blue
- Now all we have to do is describe this to Prolog
  - We tell Prolog the different colors to use for pairs of neighboring regions
  - and the neighboring regions

border(red,green).
border(red,blue).
border(green,red).
border(green,blue).
border(blue,red).
border(blue,green).

coloring(L,TAA,V,FVG) :-
    border(L,TAA),
    border(L,V),
    border(TAA,V),
    border(V,FVG).
Map Coloring/3

Querying `coloring(L,TAA,V,FVG)` will now provide all the answers:

```
?- coloring(L,TAA,V,FVG).
FVG = r
L = r
TAA = g
V = b ? ;
FVG = g
L = r
TAA = g
V = b ?
...
```
Where’s the Program?

- In Prolog you don’t have to write a program
  - You express the logic of a problem in facts and rules
  - And then let the computer do the work in figuring out a solution
- Solving the map coloring problem with a language like Java or Ruby would be (much) harder to do
- Here is the Ruby code

```ruby
def mapcoloring
  colors = [:red, :green, :blue]
  colors.each do |l|
    colors.each do |taa|
      colors.each do |v|
        colors.each do |fvg|
          if l != taa && l != v && taa != v && v != fvg then
            puts "L = #{l}, TAA = #{taa}, V = #{v}, FVG = #{fvg}"
          end
        end
      end
    end
  end
end
```
Predicates Revisited

- Predicates can be defined by a combination of facts and rules.
- We use also the term clause of a predicate to refer either to a fact or a rule defining the predicate.