Introduction to Logic Programming (Prolog)

Tutorial for

Programming Languages Laboratory (CS 431)

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Programming Paradigms

- Broadly two types
  - Imperative
  - Declarative

Imperative Programming

- We are familiar with this paradigm (procedural/OOP)
  - Main concern – ‘how’ to do things

Declarative Paradigm

- Programming is done with ‘expressions’ or ‘declarations’ rather than statements
  - Main concern – ‘what’ to do, not ‘how’

Q: Who takes care of the “How” part?

Example

demo1.pl

File Edit Browse Compile Prolog Pce Help

demo1.pl

```prolog
male(arush).
male(rahul).
male(ajay).
male(karan).

female(shivani).
female(pooja).
female(anjali).

parent(rahul,arush).
parent(rahul,pooja).
parent(ajay,karan).
parent(shivani,karan).
parent(arush,anjali).

siblings(X,Y) :- parent(Z,X),parent(Z,Y),not(X=Y).
```

Program

SWI-Prolog (AMD64, Multi-threaded, version 7.6.4)

File Edit Settings Run Debug Help

We specify “what” we need, not “how”

```
?- parent(X,karan).
X = ajay ;
X = shivani.
```

Output

Declarative Paradigm

- Logic programming – going to discuss
- Functional programming – next topic

LP - Basic

- Logic programming – centered around the idea of “formal logic”
  - Propositional logic
  - First order predicate logic
  - Higher order logic

Propositional Logic

- Simplest of all

  Proposition (premise): If it is raining it is cloudy

  Proposition (premise): It is raining

  Proposition (conclusion): It is cloudy

- Conclusion obtained by applying *modus ponens* (inference rules) on the premises ($P \rightarrow Q$; P is asserted to be true, so therefore Q must be true) - uses propositional calculus

First Order Predicate Logic (FOPL)

- Allows quantification with variables (variable values can range over a *domain of discourse*)

  PL: Socrates is a man

  FOPL: X is a man

- We are concerned about the deductive system using FOPL formulae (well-formed formulae)

  ✓ Inference using resolution refutation

FOPL

All mangoes are fruits
Alphonso is a mango
Therefore, Alphonso is fruit

More generally, in terms of wffs using FOPL notation

$\forall x, P(x) \Rightarrow Q(x)$
$P(a)$
Therefore, $Q(a)$

FOPL – Inferencing (RR)

- We can recast the inferencing process as follows to establish the same using *resolution refutation*

$\neg P(x) \vee Q(x)$
$P(a)$
Therefore, $Q(a)$

Requires conversion to CNF (Conjunctive Normal Form: "or" relation)

$P(x) \Rightarrow Q(x)$: CNF $\neg P(x) \vee Q(x)$

$\neg(P(x) \wedge Q(x))$: CNF $\neg P(x) \vee \neg Q(x)$

You can check with Truth Tables

FOPL – Inferencing (RR)

- Rules

  ✓Find two *clauses* containing the same *predicate*, where it is negated in one clause but not in the other.

  ✓Perform a *unification* on the two predicates.

  ✓If any *unbound* variables which were bound in the unified predicates also occur in other predicates in the two clauses, replace them with their bound values (terms) there as well.

  ✓Discard the unified predicates, and combine the remaining ones from the two clauses into a new clause, also joined by the "V" operator.

FOPL – Inferencing (RR)

- Apply rules to the example

$\neg$P(x) $\vee$ Q(x)
P(a)
Therefore, Q(a)

✓ Predicate P in the first clause in negated form and non-negated in the second clause; X is unbound variable and a is a bound value

✓ Unification on the two predicates resulting in *X substituted by a*

✓ Discard the unified predicate

✓ Apply substitution on the remaining clause (Q(X)) results in Q(a) [the conclusion] – hence proved

Note

- There are higher order logic also (need not bother about those here)

- We shall do some assignments in Prolog, which works on the idea of FOPL and resolution refutation

LP Perspectives

- There are many (overlapping) perspectives on logic programming
  - ✓ Computations as deduction
  - ✓ Theorem proving
  - ✓ Non-procedural programming
  - ✓ Algorithms minus control
  - ✓ A very high level programming language
  - ✓ A procedural interpretation of declarative specifications

Computation as Deduction

- Logic programming offers a slightly different paradigm for computation

  COMPUTATION IS LOGICAL DEDUCTION

- It uses the language of logic to express data and programs

  For all X and Y, X is the father of Y if
  X is a parent of Y and the gender of X is male.

Theorem Proving

- Logic Programming uses the notion of an *automatic theorem prover* as an interpreter
  - ✓ The theorem prover derives a desired solution from an initial set of axioms

- Note that the proof must be a "constructive" one so that more than a true/false answer can be obtained

  E.g. The answer to

  exists x such that x = sqrt(16)

  should be

  x = 4 or x = -4

  rather than

  true

Non-procedural Programming

- Logic Programming languages are non-procedural programming languages
  - ✓ One specifies WHAT needs to be computed but not HOW it is to be done

- That is, one specifies
  - ✓ The set of objects involved in the computation
  - ✓ The relationships which hold between them
  - ✓ The constraints which must hold for the problem to be solved

- And leaves it up the language interpreter or compiler to decide HOW to satisfy the constraints

Algorithms Minus Control

- Nikolas Wirth (architect of Pascal) used the following slogan as the title of a book
  - ✓ Algorithms + Data Structures = Programs
- Bob Kowalski offers a similar one to express the central theme of logic programming
  - ✓ Algorithms = Logic + Control
- We can view the LOGIC component as
  - ✓ A specification of the essential logical constraints of a particular problem
- And CONTROL component as
  - ✓ Advice to an evaluation machine (e.g. an interpreter or compiler) on how to go about satisfying the constraints)

A Very High Level Language

- A good programming language should not encumber the programmer with non-essential details

- The development of programming languages has been toward freeing the programmer of more and more of the details...
  - ✓ ASSEMBLY LANGUAGE: symbolic encoding of data and instructions.
  - ✓ FORTRAN: allocation of variables to memory locations, register saving, etc.
  - ✓ JAVA: Platform specifics
  - ✓ ....

- Logic Programming Languages are a class of languages which attempt to free us from having to worry about many aspects of explicit control.

A Procedural Interpretation of Declarative Specifications

- One can take a logical statement like the following
  - ✓ *For all X and Y, X is the father of Y if X is a parent of Y and the gender of X is male.*
- Which would be expressed in an LP language as
  - ✓ *father(X,Y) :- parent(X,Y), gender(X,male).*
- And interpret it in two slightly different ways
  - ✓ **Declaratively** - as a statement of the truth conditions which must be true if a father relationship holds.
  - ✓ **Procedurally** - as a description of what to do to establish that a father relationship holds.

LP Languages

- Work initiated to deal with representational issues in AI (1960s and 70s)

- Planner (MIT) – earliest language (procedural paradigm)
  - ✓ Gave rise to many languages (e.g. Popler, Conniver, QLISP, Ether)

- Prolog (one of the popular languages)
  - ✓ First system by Alain Colmerauer & Philippe Roussel (1972)

- Prolog gave rise to many new languages
  - ✓ Fril, Gödel, Mercury, Oz, Visual Prolog, λProlog …

SWI-Prolog

- SWI-Prolog is a good, standard Prolog for Windows and Linux
- It's licensed under GPL, therefore free Downloadable from:

    http://www.swi-prolog.org/

Syllogisms (Logical Reasoning) in Prolog

Syllogism	Prolog
Socrates is a man.	man(socrates).
All men are mortal.	mortal(X) :- man(X).
Is Socrates mortal?	?- mortal(socrates).

Facts, Rules and Queries

- Fact: Socrates is a man.
  man(socrates).

- Rule: All men are mortal.
  mortal(X) :- man(X).

- Query: Is Socrates mortal?
  mortal(socrates).

- Queries have the same form as facts

Prolog Basics

- Pure Prolog based on Horn clause (Alfred Horn, 1951)
- Execution of a Prolog program is initiated by the user's posting of a single goal, called the query
- Prolog engine tries to find a resolution refutation of the negated query (Selective Linear Definite or SLD resolution method - Robert Kowalski)

Prolog as Theorem Prover

- Prolog's "Yes" means "I can prove it" --
  Prolog's "No" means "I can't prove it"
  ```
  ?- mortal(plato).
        No
  ```

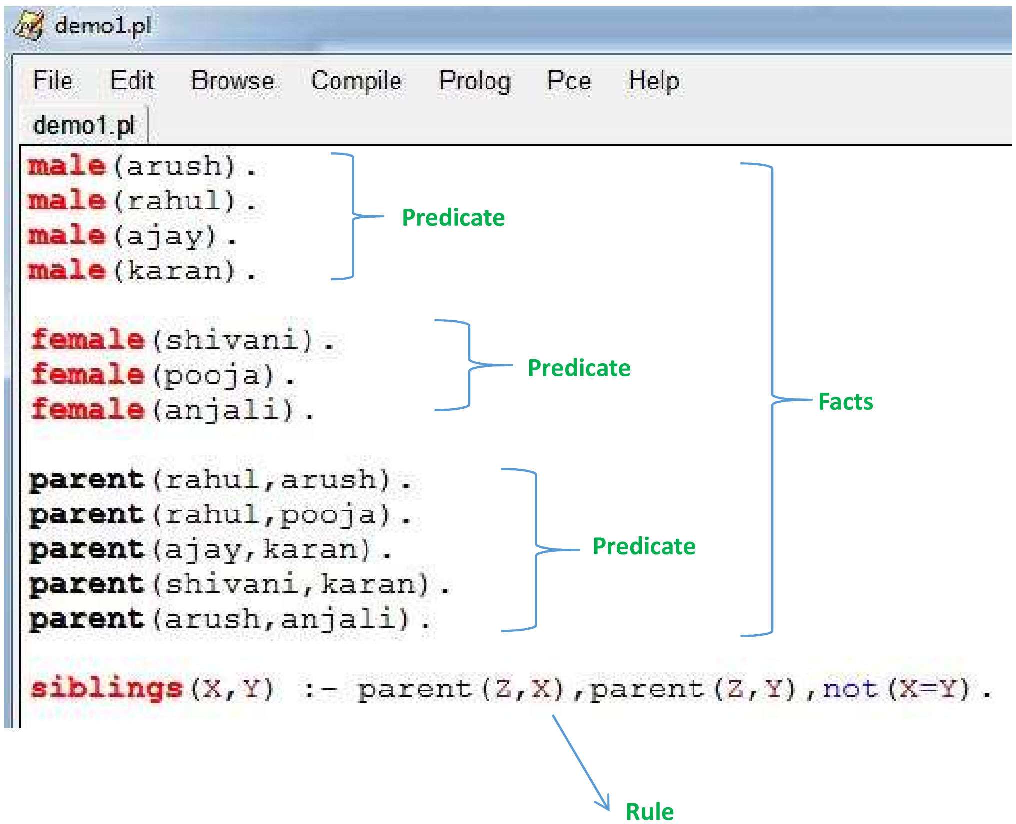
- This is the closed world assumption: the Prolog program knows everything it needs to know

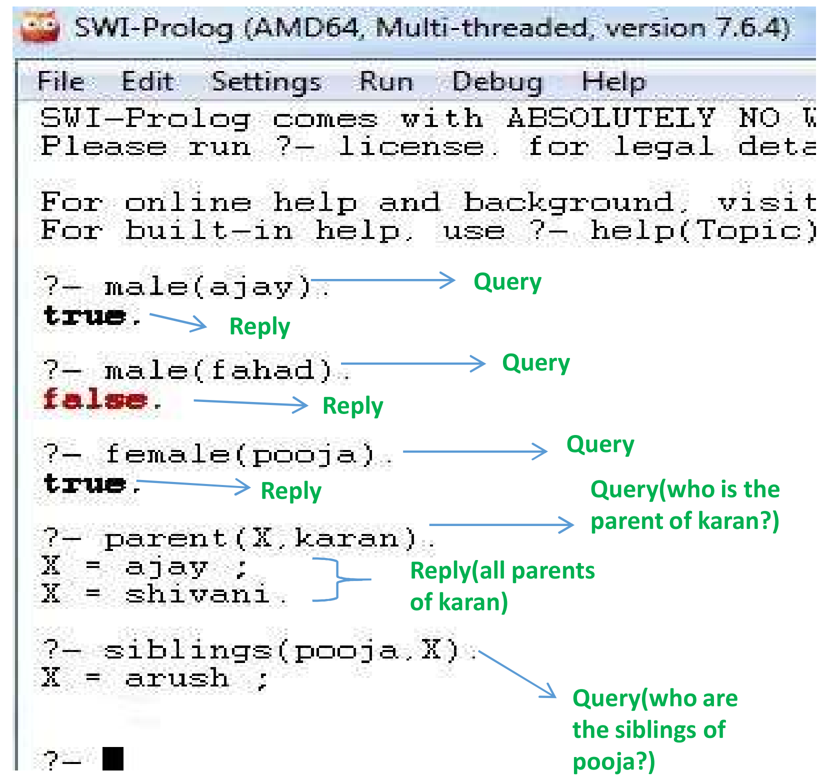
- Prolog supplies values for variables when it can
  ```
  ?- mortal(X).
        X = socrates
  ```

Structure of Programs

- Programs consist of procedures (also called predicates)
- Procedures consist of clauses
- Each clause is a fact or a rule
- Programs are executed by posing queries

Prolog: A Basic Program





Clauses: Facts and Rules

‘if’
‘provided that’
‘turnstile’

Head **:-** *Body*. This is a rule.

Head. This is a fact.

Full stop at the end.

Body of a (Rule) Clause Contains Goals

Head *Body*

likes(mary, X) :- human(X), honest(X).

Goals (comma indicates AND relation)

Interpretation of Clauses

Clauses can be given a declarative reading or a procedural reading.

Form of clause: H :- G_1, G_2, …, G_n.

Declarative reading: "That H is provable follows from goals G_1, G_2, …, G_n being provable."

Procedural reading: "To execute procedure H, the procedures called by goals G_1, G_2, …, G_n are executed first."

Another Example

```
mother_child(trude, sally).

father_child(tom, sally).
father_child(tom, erica).
father_child(mike, tom).

sibling(X, Y) :- parent_child(Z, X), parent_child(Z, Y).

parent_child(X, Y) :- father_child(X, Y).
parent_child(X, Y) :- mother_child(X, Y).
```

```
?- sibling(sally, erica).
Yes
```

How it Works

- Initially, the only matching clause-head for sibling(sally, erica) is the first rule head, so proving the query is equivalent to proving the body of that clause
- Clause proved with appropriate variable bindings, i.e., the conjunction (parent_child(Z,sally), parent_child(Z,erica)).
- The next goal to be proved is the leftmost one of this conjunction, i.e., parent_child(Z, sally).
- **Two clause heads match this goal. The system creates a choice-point and tries the first alternative, whose body is father_child(Z, sally).** **(possible backtracking point)**
- This goal can be proved using the fact father_child(tom, sally), so the binding Z = tom is generated, and the next goal to be proved is the second part of the above conjunction: parent_child(tom, erica).
- Again, this can be proved by the corresponding fact. Since all goals could be proved, the query succeeds.

Search

- Logic Programming 'procedure' can either fail or succeed

- If it succeeds, it may have computed some additional information (conveyed by instantiating variables)

  - ✓ Question: What if it fails.....? Answer: find another way to try to make it succeed
  - ✓ Most logic programming languages use a simple, fixed search strategy to try alternatives

Search

- If a goal succeeds and there are more goals to achieve, then remember any untried alternatives and go on to the next goal
- If a goal succeeds and there are no more goals to achieve, then stop with success
- If a goal fails and there are alternate ways to solve it, then try the next one
- If a goal fails and there are no alternate ways to solve it and there is a previous goal, then propagate failure back to the previous goal
- If a goal fails and there are no alternate ways to solve it and no previous goal then stop with failure.

Cuts

- A cut prunes or “cuts out” and unexplored part of a Prolog search tree
- Cuts can therefore be used to make a computation more efficient by eliminating futile searching and backtracking
- Cuts can also be used to implement a form of negation

Note

- There will be one more tutorial on Prolog (syntax) – after your midsem
- Assignments are likely to be posted by next weekend

END