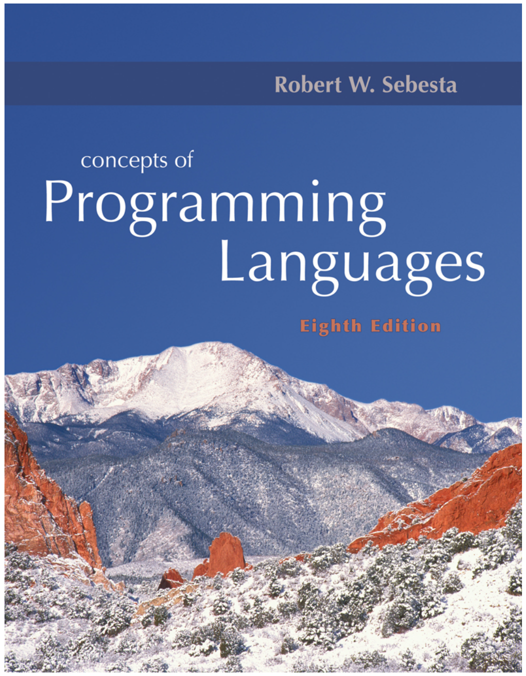
Chapter 16

Logic Programming Languages



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Chapter 16 Topics

- Introduction
- A Brief Introduction to Predicate Calculus
- Predicate Calculus and Proving Theorems
- An Overview of Logic Programming
- The Origins of Prolog
- The Basic Elements of Prolog
- Deficiencies of Prolog
- Applications of Logic Programming

Introduction

- Logic programming languages, sometimes called declarative programming languages
- Express programs in a form of symbolic logic
- Use a logical inferencing process to produce results
- Declarative rather that procedural:
  - Only specification of results are stated (not detailed procedures for producing them)

Proposition

- A logical statement that may or may not be true
  - Consists of objects and relationships of objects to each other

Symbolic Logic

- Logic which can be used for the basic needs of formal logic:
  - Express propositions
  - Express relationships between propositions
  - Describe how new propositions can be inferred from other propositions
- Particular form of symbolic logic used for logic programming called predicate calculus

Object Representation

- Objects in propositions are represented by simple terms: either constants or variables
- Constant: a symbol that represents an object
- Variable: a symbol that can represent different objects at different times
  - Different from variables in imperative languages

Compound Terms

- Atomic propositions consist of compound terms
- Compound term: one element of a mathematical relation, written like a mathematical function
  - Mathematical function is a mapping
  - Can be written as a table

Parts of a Compound Term

- Compound term composed of two parts
  - Functor: function symbol that names the relationship
  - Ordered list of parameters (tuple)
- Examples:

```
student(jon)
like(ubbo, OSX)
like(nick, windows)
like(jim, linux)
```

Forms of a Proposition

- Propositions can be stated in two forms:
  - Fact: proposition is assumed to be true
  - Query: truth of proposition is to be determined
- Compound proposition:
  - Have two or more atomic propositions
  - Propositions are connected by operators

Logical Operators

Name	Symbol	Example	Meaning
negation	¬	¬ a	not a
conjunction	$\cap$	a $\cap$ b	a and b
disjunction	$\cup$	a $\cup$ b	a or b
equivalence	≡	a ≡ b	a is equivalent to b
implication	$\supset$ $\subset$	a $\supset$ b a $\subset$ b	a implies b b implies a

Quantifiers

Name	Example	Meaning
universal	∀X.P	For all X, P is true
existential	∃X.P	There exists a value of X such that P is true

Clausal Form

- Too many ways to state the same thing
- Use a standard form for propositions
- Clausal form:
  - $B_1 \cup B_2 \cup \ldots \cup B_n \subset A_1 \cap A_2 \cap \ldots \cap A_m$
  - means if all the As are true, then at least one B is true
- Antecedent: right side
- Consequent: left side

Predicate Calculus and Proving Theorems

- A use of propositions is to discover new theorems that can be inferred from known axioms and theorems
- Resolution: an inference principle that allows inferred propositions to be computed from given propositions

Resolution

- Unification: finding values for variables in propositions that allows matching process to succeed
- Instantiation: assigning temporary values to variables to allow unification to succeed
- After instantiating a variable with a value, if matching fails, may need to backtrack and instantiate with a different value

Proof by Contradiction

- Hypotheses: a set of pertinent propositions
- Goal: negation of theorem stated as a proposition
- Theorem is proved by finding an inconsistency

Theorem Proving

- Basis for logic programming
- When propositions used for resolution, only restricted form can be used
- Horn clause – can have only two forms
  - Headed: single atomic proposition on left side
  - Headless: empty left side (used to state facts)
- Most propositions can be stated as Horn clauses

Overview of Logic Programming

- Declarative semantics
  - There is a simple way to determine the meaning of each statement
  - Simpler than the semantics of imperative languages
- Programming is nonprocedural
  - Programs do not state now a result is to be computed, but rather the form of the result

Example: Sorting a List

- Describe the characteristics of a sorted list, not the process of rearranging a list

$\text{sort(old\_list, new\_list)} \subset \text{permute (old\_list, new\_list)} \cap \text{sorted (new\_list)}$

$\text{sorted (list)} \subset \forall_j \text{ such that } 1 \leq j < n, \text{list}(j) \leq \text{list } (j+1)$

The Origins of Prolog

- University of Aix-Marseille
  - Natural language processing
- University of Edinburgh
  - Automated theorem proving

Terms

- Edinburgh Syntax
- Term: a constant, variable, or structure
- Constant: an atom or an integer
- Atom: symbolic value of Prolog
- Atom consists of either:
  - a string of letters, digits, and underscores beginning with a lowercase letter
  - a string of printable ASCII characters delimited by apostrophes

Terms: Variables and Structures

- Variable: any string of letters, digits, and underscores beginning with an uppercase letter
- Instantiation: binding of a variable to a value
  - Lasts only as long as it takes to satisfy one complete goal
- Structure: represents atomic proposition

  `functor`(parameter list)

Fact Statements

- Used for the hypotheses
- Headless Horn clauses

```
female(shelley).
male(bill).
father(bill, jake).
```


Rule Statements

- Used for the hypotheses
- Headed Horn clause
- Right side: antecedent (if part)
  - May be single term or conjunction
- Left side: consequent (then part)
  - Must be single term
- Conjunction: multiple terms separated by logical AND operations (implied)

Example Rules

```
ancestor(mary,shelley):- mother(mary,shelley).
```

- Can use variables (universal objects) to generalize meaning:

```
parent(X,Y):- mother(X,Y).
parent(X,Y):- father(X,Y).
grandparent(X,Z):- parent(X,Y), parent(Y,Z).
sibling(X,Y):- mother(M,X), mother(M,Y),
               father(F,X), father(F,Y).
```

Goal Statements

- For theorem proving, theorem is in form of proposition that we want system to prove or disprove – goal statement
- Same format as headless Horn

```
man(fred)
```

- Conjunctive propositions and propositions with variables also legal goals

```
father(X,mike)
```


Inferencing Process of Prolog

- Queries are called goals
- If a goal is a compound proposition, each of the facts is a subgoal
- To prove a goal is true, must find a chain of inference rules and/or facts. For goal Q:

```
B :- A
C :- B
…
Q :- P
```

- Process of proving a subgoal called matching, satisfying, or resolution

Approaches

- Bottom-up resolution, forward chaining
  - Begin with facts and rules of database and attempt to find sequence that leads to goal
  - Works well with a large set of possibly correct answers
- Top-down resolution, backward chaining
  - Begin with goal and attempt to find sequence that leads to set of facts in database
  - Works well with a small set of possibly correct answers
- Prolog implementations use backward chaining

Subgoal Strategies

- When goal has more than one subgoal, can use either
  - Depth-first search: find a complete proof for the first subgoal before working on others
  - Breadth-first search: work on all subgoals in parallel
- Prolog uses depth-first search
  - Can be done with fewer computer resources

Backtracking

- With a goal with multiple subgoals, if fail to show truth of one of subgoals, reconsider previous subgoal to find an alternative solution: backtracking
- Begin search where previous search left off
- Can take lots of time and space because may find all possible proofs to every subgoal

Simple Arithmetic

- Prolog supports integer variables and integer arithmetic
- `is` operator: takes an arithmetic expression as right operand and variable as left operand

```
A is B / 17 + C
```

- Not the same as an assignment statement!

Example

```
speed(ford,100).
speed(chevy,105).
speed(dodge,95).
speed(volvo,80).
time(ford,20).
time(chevy,21).
time(dodge,24).
time(volvo,24).
distance(X,Y) :-  speed(X,Speed),
                  time(X,Time),
                  Y is Speed * Time.
```

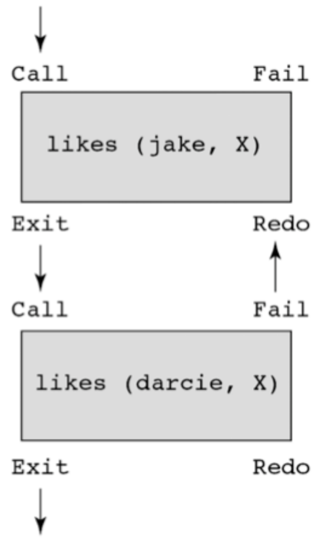

Trace

- Built-in structure that displays instantiations at each step
- Tracing model of execution – four events:
  - Call (beginning of attempt to satisfy goal)
  - Exit (when a goal has been satisfied)
  - Redo (when backtrack occurs)
  - Fail (when goal fails)

Example

```
likes(jake,chocolate).
likes(jake,apricots).
likes(darcie,licorice).
likes(darcie,apricots).

trace.
likes(jake,X),
likes(darcie,X).
```

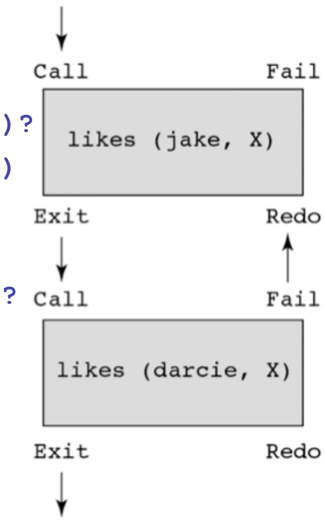


Control flow model for the goal `likes (jake, X), likes (darcie, X)`

Example

```
likes(jake,chocolate).
likes(jake,apricots).
likes(darcie,licorice).
likes(darcie,apricots).
```

```
(1) 1 Call: likes(jake,_0)?
(1) 1 Exit: likes(jake,chocolate)
(2) 1 Call: likes(darcie,chocolate)?
(2) 1 Fail: likes(darcie,chocolate)
(1) 1 Redo: likes(jake,_0)?
(1) 1 Exit: likes(jake,apricots)
(3) 1 Call: likes(darcie,apricots)?
(3) 1 Exit: likes(darcie,apricots)
```



Control flow model for the goal `likes (jake, X), likes (darcie, X)`

List Structures

- Other basic data structure (besides atomic propositions we have already seen): list
- List is a sequence of any number of elements
- Elements can be atoms, atomic propositions, or other terms (including other lists)

`[apple, prune, grape, kumquat]`

`[]` (empty list)

`[X | Y]` (head X and tail Y)

Append Example

```
append([], List, List).
append([Head|List_1],List_2,[Head|List_3]) :-
append(List_1, List_2, List_3).
```

Reverse Example

```
reverse([],[]).
reverse([Head|Tail],List) :-
reverse(Tail, Result),
append(Result,[Head],List).
```


Deficiencies of Prolog

- Resolution order control
- The closed-world assumption
- The negation problem
- Intrinsic limitations

Applications of Logic Programming

- Relational database management systems
- Expert systems
- Natural language processing

Summary

- Symbolic logic provides basis for logic programming
- Logic programs should be nonprocedural
- Prolog statements are facts, rules, or goals
- Resolution is the primary activity of a Prolog interpreter
- Although there are a number of drawbacks with the current state of logic programming it has been used in a number of areas