CSc 372

Comparative Programming Languages

17 : Prolog — Introduction

Department of Computer Science
University of Arizona

collberg@gmail.com

Christian Collberg

What is Prolog?

What is Prolog?

- Prolog is a language which approaches problem-solving in a *declarative* manner. The idea is to define *what* the problem is, rather than *how* it should be solved.
- In practice, most Prolog programs have a procedural as well as a declarative component — the procedural aspects are often necessary in order to make the programs execute efficiently.

What is Prolog?

Algorithm = Logic + Control   Robert A. Kowalski

Prescriptive Languages:

- Describe *how* to solve problem
- Pascal, C, Ada,...
- Also: Imperative, Procedural

Descriptive Languages:

- Describe *what* should be done
- Also: Declarative

Kowalski's equation says that

- Logic – is the specification (what the program should do)
- Control – what we need to do in order to make our logic execute efficiently. This usually includes imposing an execution order on the rules that make up our program.

Objects & Relationships

Objects & Relationships

Prolog programs deal with

- objects, and
- relationships between objects

English:

“Christian likes the record”

Prolog:

```
likes(christian, record).
```

Facts

Record Database

- Here’s an excerpt from Christian’s record database:

```
is_record(planet_waves).
is_record(desire).
is_record(slow_train).

recorded_by(planet_waves, bob_dylan).
recorded_by(desire, bob_dylan).
recorded_by(slow_train, bob_dylan).

recording_year(planet_waves, 1974).
recording_year(desire, 1975).
recording_year(slow_train, 1979).
```

Record Database...

- The data base contains *unary facts* (`is_record`) and *binary facts* (`recorded_by, recording_year`).
- The fact

  `is_record(slow_train)`

  can be interpreted as

  `slow_train` *`is-a-record`*
- The fact `recording_year(slow_train, 1979)` can be interpreted as *the recording year of slow_train was 1979.*

Conditional Relationships

Conditional Relationships

- Prolog programs deal with conditional relationships between objects.

English:

"C. likes Bob Dylan records recorded before 1979"

Prolog:

```
likes(christian, X) :-
      is_record(X),
      recorded_by(X, bob_dylan),
      recording_year(X, Year),
      Year < 1979.
```

Conditional Relationships...

- The rule

  ```
  likes(christian, X) :-
        is_record(X),
        recorded_by(X, bob_dylan),
        recording_year(X, Year),
        Year < 1979.
  ```

  can be restated as

  > *"Christian likes* `X`*, if* `X` *is a record, and* `X` *is recorded by Bob Dylan, and the recording year is before 1979."*

- Variables start with capital letters.
- Comma (",") is read as *and*.

Asking Questions

Asking Questions

Prolog programs

- solve problems by asking questions.

English:

“Does Christian like the albums Planet Waves *&* Slow Train*?’*

Prolog:

```
?- likes(christian, planet_waves).
yes
?- likes(christian, slow_train).
no
```

Asking Questions...

English:

“Was Planet Waves *recorded by Bob Dylan?”*
“When was Planet Waves *recorded?”*
“Which album was recorded in 1974?”

Prolog:

```
?- recorded_by(planet_waves, bob_dylan).
   yes

?- recording_year(planet_waves, X).
   X = 1974

?- recording_year(X, 1974).
   X = planet_waves
```

Asking Questions...

In Prolog

- "," (a comma), means "and’

English:

“Did Bob Dylan record an album in 1974?”

Prolog:

```
?- is_record(X),
      recorded_by(X, bob_dylan),
      recording_year(X, 1974).
yes
```

Asking Questions. . .

Sometimes a query has more than one answer:

- Use ";" to get all answers.

English:

"What does Christian like?"

Prolog:

```
?- likes(christian, X).
   X = planet_waves ;

   X = desire ;

no
```

Asking Questions. . .

Sometimes answers have more than one part:

English:

"List the albums and their artists!"

Prolog:

```
?- is_record(X), recorded_by(X, Y).
X = planet_waves,
Y = bob_dylan ;
X = desire,
Y = bob_dylan ;
X = slow_train,
Y = bob_dylan ;
no
```

Recursive Rules

Recursive Rules

"People are influenced by the music they listen to.
People are influenced by the music listened to by the *people* they *listen to."*

```
listens_to(bob_dylan, woody_guthrie).
listens_to(arlo_guthrie, woody_guthrie).
listens_to(van_morrison, bob_dylan).
listens_to(dire_straits, bob_dylan).
listens_to(bruce_springsteen, bob_dylan).
listens_to(björk, bruce_springsteen).

influenced_by(X, Y) :- listens_to(X, Y).
influenced_by(X, Y) :- listens_to(X,Z),
                       influenced_by(Z,Y).
```

Asking Questions. . .

English:

"Is Björk influenced by Bob Dylan?"
"Is Björk influenced by Woody Guthrie?"
"Is Bob Dylan influenced by Bruce Springsteen?"

Prolog:

```
?- influenced_by(bjork, bob_dylan).
yes
?- influenced_by(bjork, woody_guthrie).
yes
?- influenced_by(bob_dylan, bruce_s).
no
```

Visualizing Logic

- *Comma* (,) is read as and in Prolog. Example: The rule

  ```
  person(X) :- has_bellybutton(X), not_dead(X).
  ```

  is read as

  "X is a person if X has a bellybutton and X is not dead."

- *Semicolon* (;) is read as or in Prolog. The rule

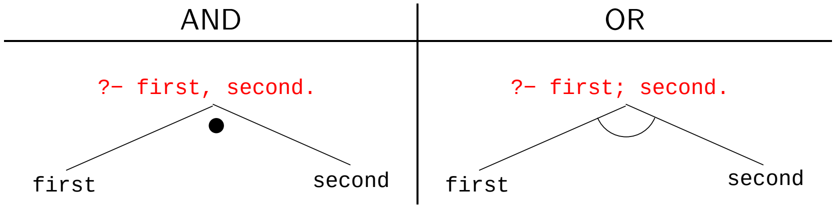
  ```
  person(X) :- X=adam ; X=eve ;
                    has_bellybutton(X).
  ```

  is read as

  "X is a person if X is adam or X is eve or X has a bellybutton."

Visualizing Logic. . .

- To visualize what happens when Prolog executes (and this can often be very complicated!) we use the following two notations:

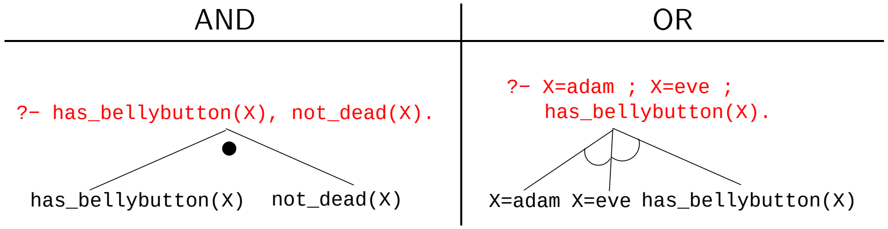


```
?- first, second.
?- first; second.
```

- For AND, both legs have to succeed.
- For OR, one of the legs has to succeed.

Visualizing Logic. . .

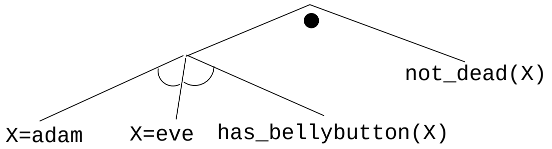
- Here are two examples:



```
?- has_bellybutton(X), not_dead(X).
?- X=adam ; X=eve ;
   has_bellybutton(X).
```

Visualizing Logic. . .

- and and or can be combined:
  `?- (X=adam ; X=eve ; has_bellybutton(X)), not_dead(X).`



not_dead(X)

X=adam X=eve has_bellybutton(X)

- This query asks

  "Is there a person X who is adam, eve, or who has a bellybutton, and who is also not dead?"

How does Prolog Answer Questions?

Answering Questions

```
(1)   scientist(helder).
(2)   scientist(ron).
(3)   portuguese(helder).
(4)   american(ron).
(5)   logician(X) :- scientist(X).
(6)   ?- logician(X), american(X).
```

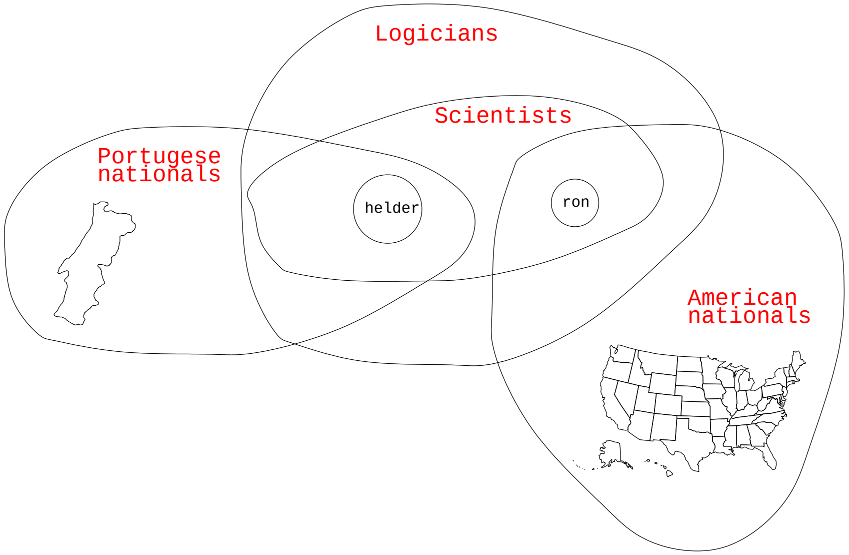
- The rule (5) states that

  "Every scientist is a logician"

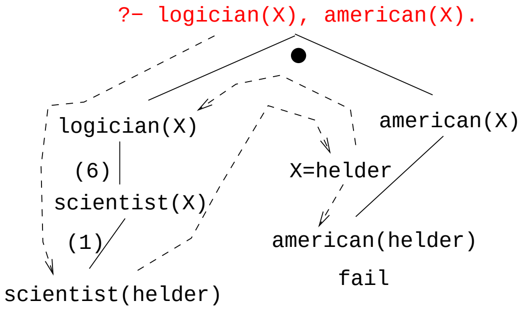
- The question (6) asks

  "Which scientist is a logician and *an american?"*

Answering Questions. . .

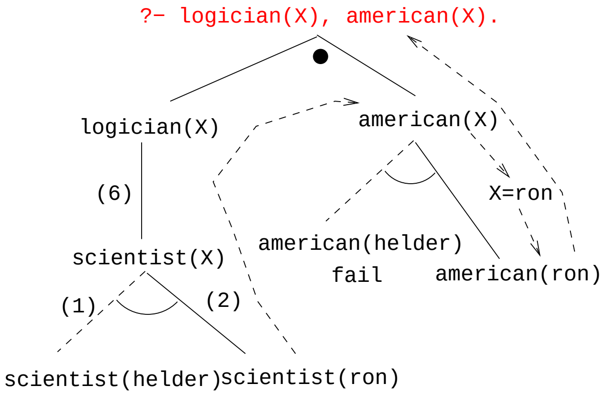


Answering Questions. . .



```
(1)   scientist(helder).
(2)   scientist(ron).
(3)   portuguese(helder).
(4)   american(ron).
(5)   logician(X) :- scientist(X).
(6)   ?- logician(X), american(X).
```

Answering Questions. . .



Answering Questions. . .

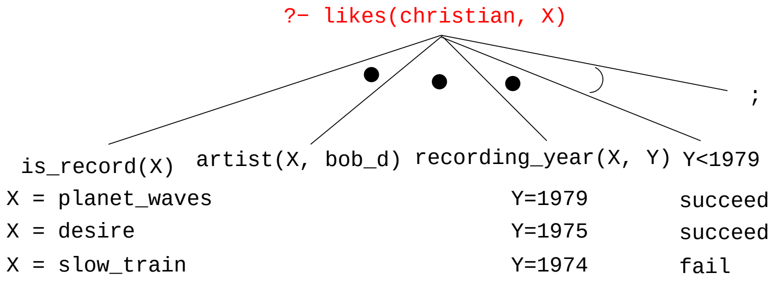
```
is_record(planet_waves).  is_record(desire).
is_record(slow_train).

recorded_by(planet_waves, bob_dylan).
recorded_by(desire, bob_dylan).
recorded_by(slow_train, bob_dylan).

recording_year(planet_waves, 1974).
recording_year(desire, 1975).
recording_year(slow_train, 1979).

likes(christian, X) :-
      is_record(X), recorded_by(X, bob_dylan),
      recording_year(X, Year), Year < 1979.
```

Answering Questions. . .



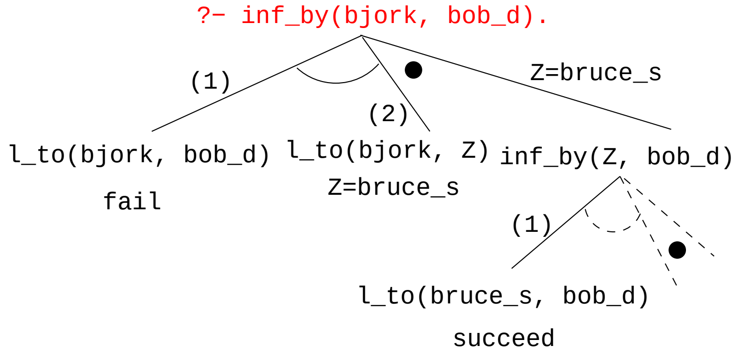
Answering Questions. . .

```
listens_to(bob_dylan, woody_guthrie).
listens_to(arlo_guthrie, woody_guthrie).
listens_to(van_morrison, bob_dylan).
listens_to(dire_straits, bob_dylan).
listens_to(bruce_springsteen, bob_dylan).
listens_to(björk, bruce_springsteen).

(1)   influenced_by(X, Y) :- listens_to(X, Y).
(2)   influenced_by(X, Y) :-
         listens_to(X, Z),
         influenced_by(Z, Y).

?- influenced_by(bjork, bob_dylan).
?- inf_by(bjork, woody_guthrie).
```

Answering Questions. . .



?- inf_by(bjork, bob_d).

(1)

(2)

Z=bruce_s

l_to(bjork, bob_d)

fail

l_to(bjork, Z)

Z=bruce_s

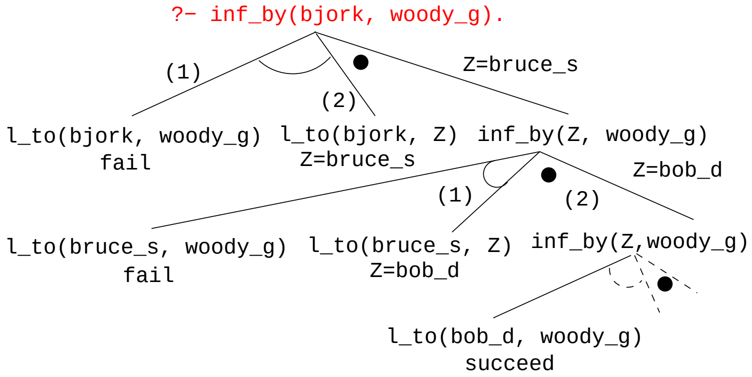
inf_by(Z, bob_d)

(1)

l_to(bruce_s, bob_d)

succeed

Answering Questions. . .



?- inf_by(bjork, woody_g).

(1)

(2)

Z=bruce_s

l_to(bjork, woody_g)

fail

l_to(bjork, Z)

Z=bruce_s

inf_by(Z, woody_g)

Z=bob_d

(1)

(2)

l_to(bruce_s, woody_g)

fail

l_to(bruce_s, Z)

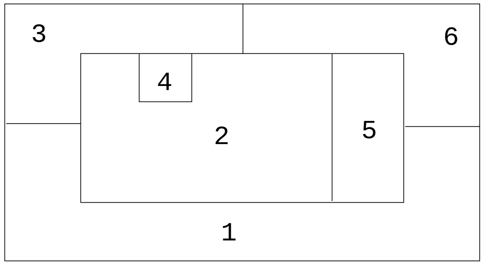
Z=bob_d

inf_by(Z,woody_g)

l_to(bob_d, woody_g)

succeed

Map Coloring



"Color a planar map with at most four colors, so that contiguous regions are colored differently."

Map Coloring. . .

A coloring is OK iff

1. The color of Region 1 ≠ the color of Region 2, and
2. The color of Region 1 ≠ the color of Region 3,...

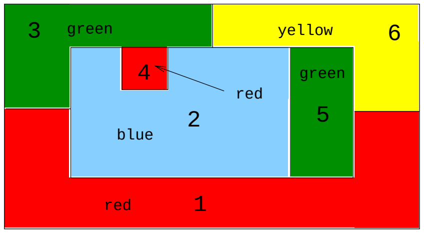
```
color(R1, R2, R3, R4, R5, R6) :-
   diff(R1, R2), diff(R1, R3), diff(R1, R5), diff(R1, R6),
   diff(R2, R3), diff(R2, R4), diff(R2, R5), diff(R2, R6),
   diff(R3, R4), diff(R3, R6), diff(R5, R6).

diff(red,blue).  diff(red,green).  diff(red,yellow).
diff(blue,red).  diff(blue,green).  diff(blue,yellow).
diff(green,red).  diff(green,blue).  diff(green,yellow).
diff(yellow, red).diff(yellow,blue).  diff(yellow,green).
```

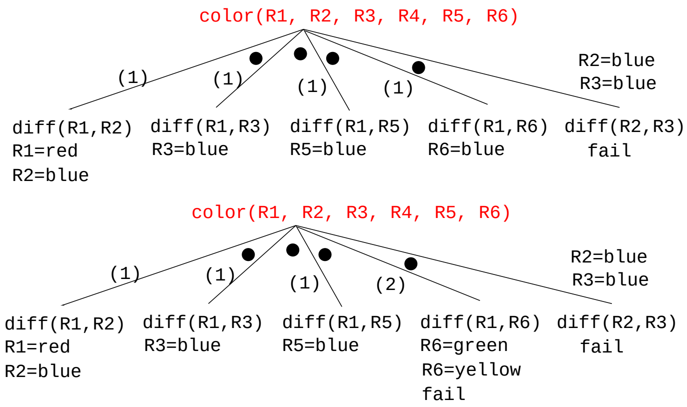
Map Coloring. . .

```
?- color(R1, R2, R3, R4, R5, R6).
R1 = R4 = red, R2 = blue,
R3 = R5 = green, R6 = yellow ;

R1 = red, R2 = blue,
R3 = R5 = green, R4 = R6 = yellow
```



Map Coloring – Backtracking



color(R1, R2, R3, R4, R5, R6)

(1) (1) (1) (1)

R2=blue
R3=blue

diff(R1,R2)
R1=red
R2=blue

diff(R1,R3)
R3=blue

diff(R1,R5)
R5=blue

diff(R1,R6)
R6=blue

diff(R2,R3)
fail

color(R1, R2, R3, R4, R5, R6)

(1) (1) (1) (2)

R2=blue
R3=blue

diff(R1,R2)
R1=red
R2=blue

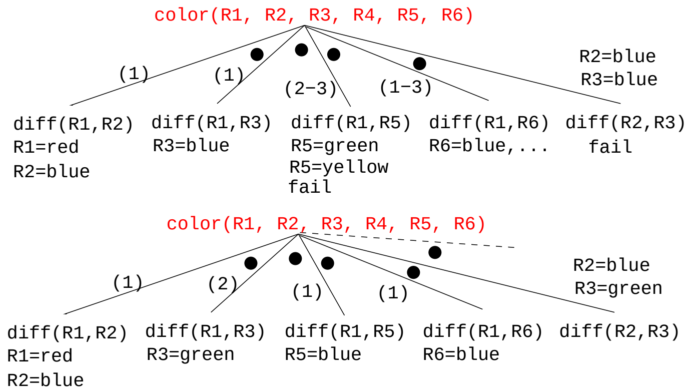
diff(R1,R3)
R3=blue

diff(R1,R5)
R5=blue

diff(R1,R6)
R6=green
R6=yellow
fail

diff(R2,R3)
fail

Map Coloring – Backtracking



color(R1, R2, R3, R4, R5, R6)

(1) (1) (2–3) (1–3)

R2=blue
R3=blue

diff(R1,R2)
R1=red
R2=blue

diff(R1,R3)
R3=blue

diff(R1,R5)
R5=green
R5=yellow
fail

diff(R1,R6)
R6=blue,...

diff(R2,R3)
fail

color(R1, R2, R3, R4, R5, R6)

(1) (2) (1) (1)

R2=blue
R3=green

diff(R1,R2)
R1=red
R2=blue

diff(R1,R3)
R3=green

diff(R1,R5)
R5=blue

diff(R1,R6)
R6=blue

diff(R2,R3)

Working with gprolog

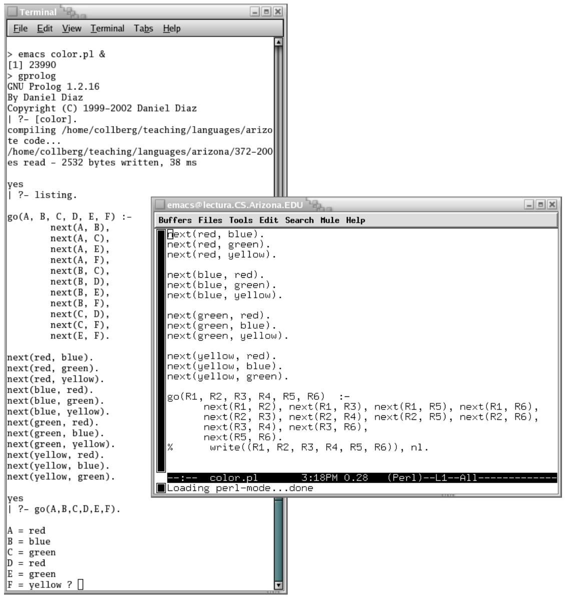
- gprolog can be downloaded from here: http://gprolog.inria.fr/.
- gprolog is installed on lectura (it's also on the Windows machines) and is invoked like this:

```
> gprolog
GNU Prolog 1.2.16
| ?- [color].
| ?- listing.
go(A, B, C, D, E, F) :- next(A, B), ...
| ?- go(A,B,C,D,E,F).
A = red ...
```

Working with gprolog. . .

- The command [color] loads the prolog program in the file color.pl.
- You should use the texteditor of your choice (emacs, vi,...) to write your prolog code.
- The command listing lists all the prolog predicates you have loaded.

Working with gprolog. . .


Terminal
File Edit View Terminal Tabs Help
emacs@lectura.CS.Arizona.EDU
Buffers Files Tools Edit Search Mule Help

```
> emacs color.pl &
[1] 23990
> gprolog
GNU Prolog 1.2.16
By Daniel Diaz
Copyright (C) 1999-2002 Daniel Diaz
| ?- [color].
compiling /home/collberg/teaching/languages/arizo
te code...
/home/collberg/teaching/languages/arizona/372-200
es read - 2532 bytes written, 38 ms

yes
| ?- listing.

go(A, B, C, D, E, F) :-
        next(A, B),
        next(A, C),
        next(A, E),
        next(A, F),
        next(B, C),
        next(B, D),
        next(B, E),
        next(B, F),
        next(C, D),
        next(C, F),
        next(E, F).

next(red, blue).
next(red, green).
next(red, yellow).
next(blue, red).
next(blue, green).
next(blue, yellow).
next(green, red).
next(green, blue).
next(green, yellow).
next(yellow, red).
next(yellow, blue).
next(yellow, green).

yes
| ?- go(A,B,C,D,E,F).

A = red
B = blue
C = green
D = red
E = green
F = yellow ?
```

```
next(red, blue).
next(red, green).
next(red, yellow).

next(blue, red).
next(blue, green).
next(blue, yellow).

next(green, red).
next(green, blue).
next(green, yellow).

next(yellow, red).
next(yellow, blue).
next(yellow, green).

go(R1, R2, R3, R4, R5, R6)  :-
      next(R1, R2), next(R1, R3), next(R1, R5), next(R1, R6),
      next(R2, R3), next(R2, R4), next(R2, R5), next(R2, R6),
      next(R3, R4), next(R3, R6),
      next(R5, R6).
%      write((R1, R2, R3, R4, R5, R6)), nl.

--:--  color.pl       3:18PM 0.28   (Perl)--L1--All-------------
Loading perl-mode...done
```

Readings and References

- Read Clocksin-Mellish, Chapter 1-2.
- http://dmoz.org/Computers/Programming/Languages/Prolog

Prolog by Example	Coelho & Cotta
Prolog: Programming for AI	Bratko
Programming in Prolog	Clocksin & Mellish
The Craft of Prolog	O'Keefe
Prolog for Programmers	Kluzniak & Szpakowicz
Prolog	Alan G. Hamilton
The Art of Prolog	Sterling & Shapiro

Readings and References. . .

Computing with Logic	Maier & Warren
Knowledge Systems Through Prolog	Steven H. Kim
Natural Language Processing in Prolog	Gazdar & Mellish
Language as a Cognitive Process	Winograd
Prolog and Natural Language Analysis	Pereira and Shieber
Computers and Human Language	George W. Smith
Introduction to Logic	Irving M. Copi
Beginning Logic	E.J.Lemmon

Prolog So Far

- A Prolog program consists of a number of *clauses*:

  Rules
  - Have `head` + `body`:

    $$\overbrace{\texttt{likes(chris, X)}}^{\text{head}}\ \texttt{:-}$$
    $$\underbrace{\texttt{girl(X), black\_hair(X)}}_{\text{body}}$$

  - Can be recursive

  Facts
  - Head but no body.
  - Always true.

Prolog So Far. . .

- A clause consists of

  atoms Start with lower-case letter.

  variables Start with upper-case letter.
- Prolog programs have a
  - Declarative meaning
    - The relations defined by the program
  - Procedural meaning
    - The order in which goals are tried

Prolog So Far. . .

- A question consists of one or more goals:
  - `?- likes(chris, X), smart(X).`
  - "," means and
  - Use ";" to get all answers
  - Questions are either
    - Satisfiable (the goal succeeds)
    - Unsatisfiable (the goal fails)
  - Prolog answers questions (satisfies goals) by:
    - instantiating variables
    - searching the database sequentially
    - backtracking when a goal fails