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07.363

Functional and Logic Programming

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Introduction

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

Slide 1–1

Objects & Relationships I

Prolog programs deal with

- objects, and
- relationships between objects

English:

"Christian likes the record"

Prolog:

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

Slide 1–2

Record Database I

```
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).
```

Slide 1–3

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.
```

Slide 1–4

Asking Questions I

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
```

Slide 1–5

Asking Questions II

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_d).
   yes

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

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

Slide 1–6

Asking Questions III

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
```

Slide 1–7

Asking Questions IV

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
```

Slide 1–8

Asking Questions V

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
```

Slide 1–9

Recursive Rules I

"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_guth..).
listens_to(van_morrison, bob_dylan).
listens_to(dire_straits, bob_dylan).
listens_to(bruce_springsteen, bob_d..).
listens_to(björk, bruce_springsteen).

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

Slide 1–10

Asking Questions VI

English:

"Is Björk influenced by Bob Dylan?"

"Is Björk influenced by Woody Guthrie?"

"Is Bob Dylan influenced by Bruce Springsteen?"

Prolog:

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

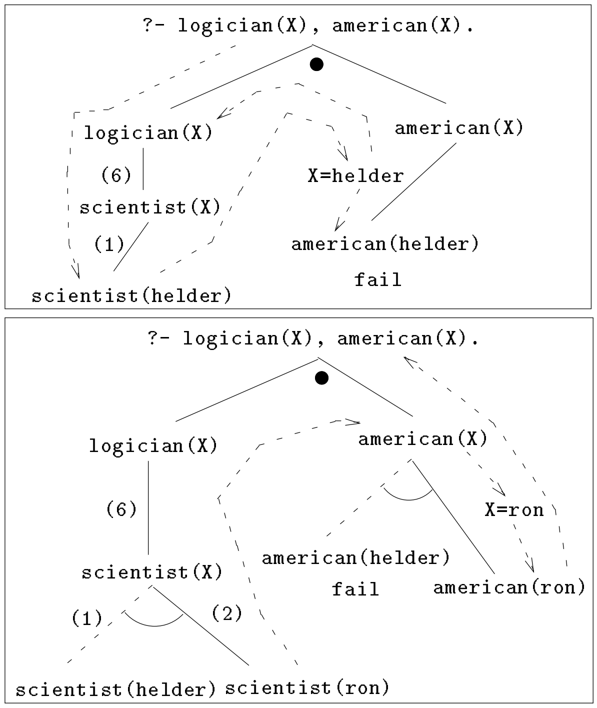
Slide 1–11

Answering Questions I

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

Slide 1–12

Answering Questions II



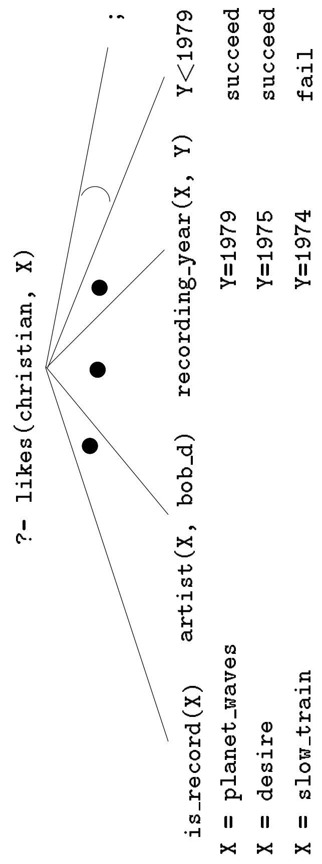
Slide 1–13

Answering Questions III

```
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.
```

Slide 1–14

Answering Questions IV



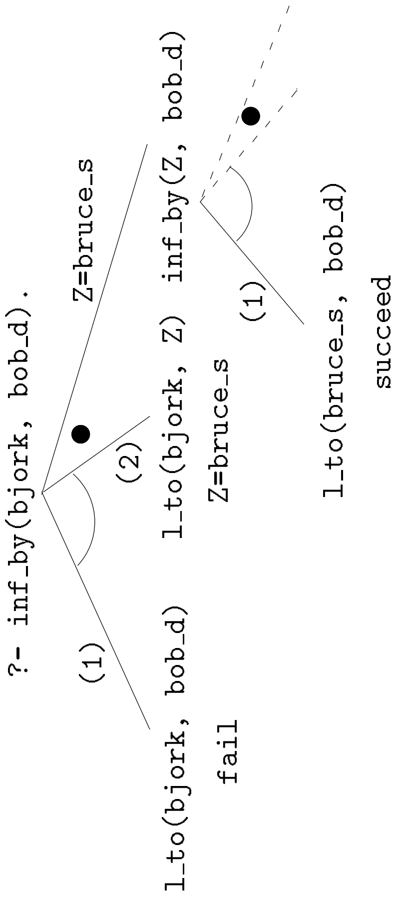
Slide 1–15

Answering Questions V

```
listens_to(bob_dylan, woody_g).
listens_to(arlo_guthrie, woody_g).
listens_to(van_morrison, bob_d).
listens_to(dire_straits, bob_d).
listens_to(bruce_springsteen, bob_d).
listens_to(björk, bruce_s) .

(1)   inf_by(X, Y) :- l_to(X, Y).
(2)   inf_by(X, Y) :-
          l_to(X, Z),
          inf_by(Z, Y).

?- inf_by(bjork, bob_d).
?- inf_by(bjork, woody_g).
```

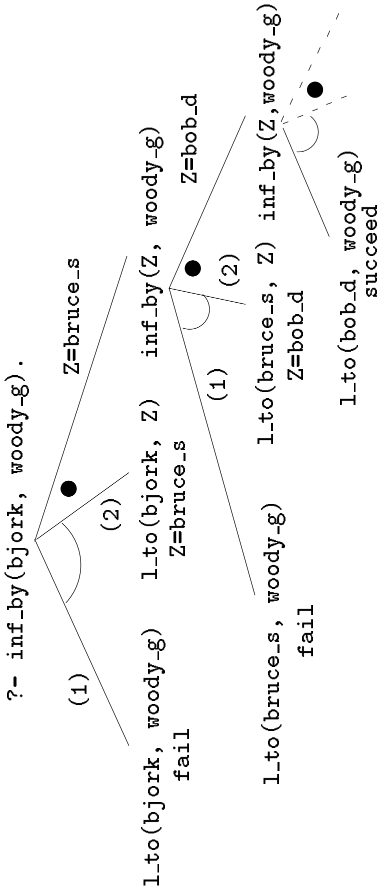
Slide 1–16

Answering Questions VI



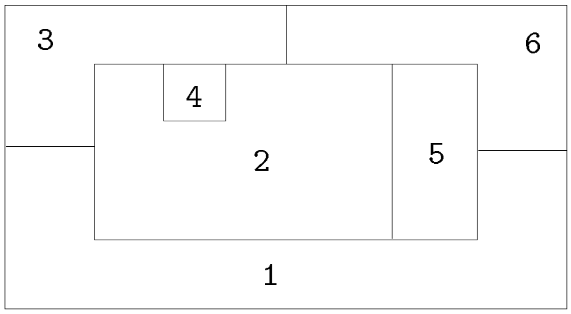
Slide 1–17

Answering Questions VII



Slide 1–18

Map Coloring I



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

Slide 1–19

Map Coloring II

A coloring is OK iff

1. The color of Region 1 $\neq$ the color of Region 2, and
2. The color of Region 1 $\neq$ 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).
```

Slide 1–20

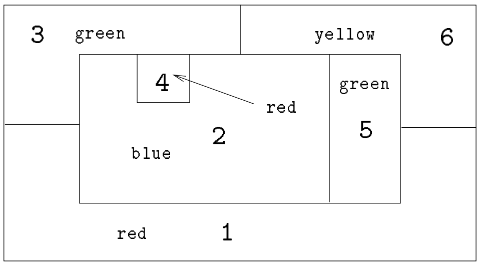
Map Coloring III

```
(1)   diff(red, blue).
(2)   diff(red, green).
(3)   diff(red, yellow).

(4)   diff(blue, red).
(5)   diff(blue, green).
(6)   diff(blue, yellow).

(7)   diff(green, red).
(8)   diff(green, blue).
(9)   diff(green, yellow).

(10)  diff(yellow, red).
(11)  diff(yellow, blue).
(12)  diff(yellow, green).
```

Slide 1–21

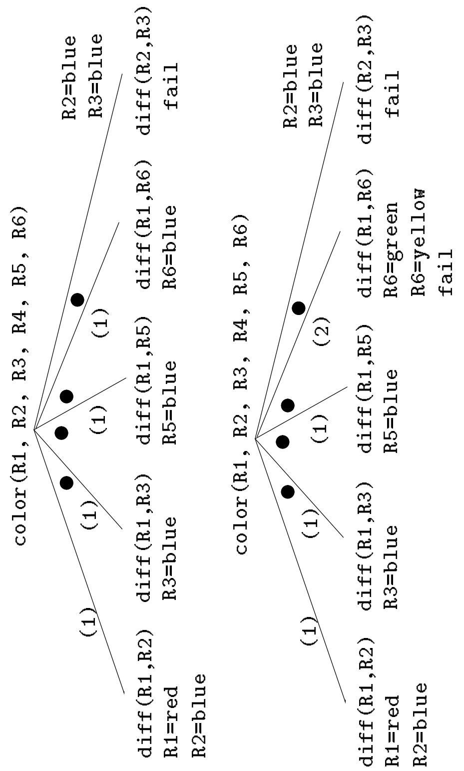
Map Coloring IV

```
?- 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
```



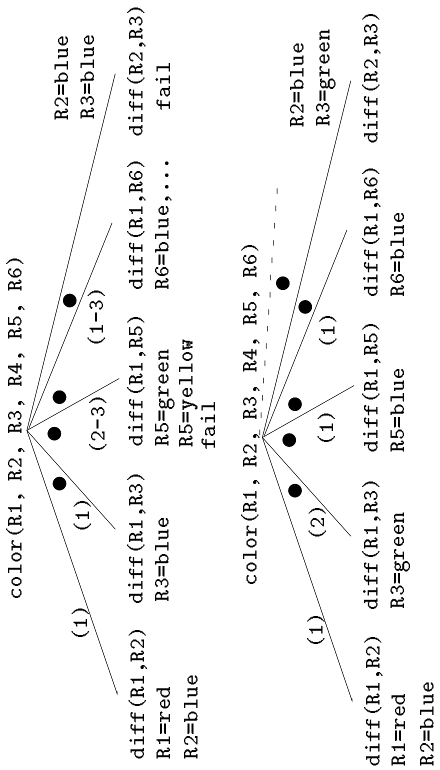
Slide 1–22

Map Coloring V – Backtracking



Slide 1–23

Map Coloring VI – Backtracking



Slide 1–24

Prolog So Far I (a)

- 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.

Slide 1–25

Prolog So Far I (b)

- 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

Slide 1–26

Prolog So Far I (c)

- 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

Slide 1–27