

# *Logic Programming*

## *The Basics*

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# Contents

## Basics of PROLOG

Facts

Questions

Variables

Conjunction

Rules

# PROLOG

Used to solve problems involving

- ▶ objects, and
- ▶ relationships between objects.

# Relationships

## Example

John owns the book

- ▶ The relationship: *ownership*
- ▶ The objects: *book, John*

Directional:

- ▶ John owns the book
- ▶ **Not:** The book owns John

# Questions

## Example

Does John own the book?

Asks a question about a relationship already established.

# Rules

Describe Relationships Using other Relationships.

## Example

Two people are sisters if they are both female and have the same parents.

Gives a definition of one relationship given other relationships.

- ▶ Both must be females.
- ▶ Both must have the same parents.
- ▶ If two people satisfy these rules, then they are sisters (according to our simplified relationship)

# Programming in PROLOG

- ▶ **Declaring Facts** about objects and their relationships.
- ▶ **Defining Rules** about objects and their relationships.
- ▶ **Asking Questions** about objects and their relationships.

# PROLOG

- ▶ Program can be thought of as a storehouse of facts and rules.
- ▶ Conversational Language: The user can ask questions about the set of facts and rules in the PROLOG program.

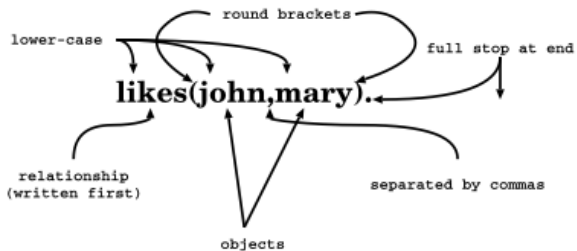


# PROLOG

## Sisters Example:

- ▶ A rule defining sisters and the facts about the people involved.
- ▶ The user would ask:  
**Are these two people sisters?**
- ▶ The system would answer  
**yes** (true) or **no** (false)

# Parts of Fact



# Order of Objects

`likes(mary, john) .`

order defined by programmer

`mary`  $\xrightarrow{\text{likes}}$  `john`

The fact says nothing  
about how john likes mary

`john . . . no info . . .`  $\blacktriangleright$  `mary`

# Examples of Facts

## Example

**Gold is valuable.**

`valuable(gold)`

**Jane is a female.**

`female(jane)`

**John owns some gold.**

`owns(john, gold)`

**John is the father of Mary.**

`father(john, mary)`

# Examples of Facts

## Example

**Gold is valuable.**

`valuable(gold)`

**Jane is a female.**

`female(jane)`

**John owns some gold.**

`owns(john, gold)`

**John is the father of Mary.**

`father(john, mary)`

Are these expressions really facts? Is there anything missing?

# Interpretation of Names

The name refers to an object.

- ▶ **Semantic Meaning:** Given by the programmer.
- ▶ **Syntactic Meaning:** a set of characters, as PROLOG sees it.

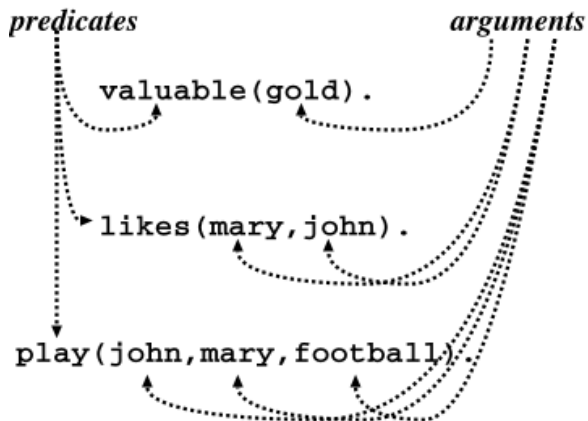
# Interpretation of Names

Name refers to an object.

- ▶ Name `gold` can refer to:
  - ▶ a particular lump of gold, or
  - ▶ the chemical element Gold having atomic number 79.
- ▶ `valuable(gold)` can mean:
  - ▶ that particular lump of gold, named `gold`, is valuable, or
  - ▶ the chemical element Gold, named `gold`, is valuable.

The programmer decides (in her usage) the meaning.

# Fact Terminology





# Database

## Definition

In PROLOG, **database** is a collection of facts.

- ▶ PROLOG draws its knowledge from these facts.
- ▶ The programmer is responsible for their accuracy.

# Questions

- ▶ The database contains the facts from which the questions are answered.
- ▶ A Question can look exactly like a fact:  
`owns (mary, book) .`
- ▶ The difference is in which mode one is in

# Questions

In the interactive question mode (indicated by the question mark and dash ?-):

- ▶ Question: ?- owns(mary, book) .
- ▶ Meaning:
  - ▶ If `mary` is interpreted as a person called Mary, and `book` is interpreted as some particular book, then
  - ▶ ?- owns(mary, book) . means: **Does Mary own the book?**

# Database Search

## Example

Facts in the database:

```
likes(joe, fish) .
```

```
likes(joe, mary) .
```

```
likes(mary, book) .
```

```
likes(john, book) .
```

Questions:

```
?- likes(joe, money) .
```

no

```
?- likes(joe, mary) .
```

yes

```
?- king(john, france) .
```

no

# Knowledge

The questions are always answered with respect to the database.

## Example

Facts in the database:

```
human(socrates) .  
human(aristotle) .  
athenian(socrates) .
```

Question:

Is Socrates Greek?

```
?- greek(socrates)
```

The answer with respect to this database is **No**.

# Questions

Up until now questions just reflect exactly the database.

Does Mary like the book?

```
?- likes(mary,book) .
```

More Interesting Question:  
What objects does Mary like?

Variables.

# Variables

Tiresome to ask about every object:

```
likes(john, this)
```

```
likes(john, that)
```

Better to ask:

What does John like?

or

Does John like X?

(i.e. use variables)

## Question With Variables

Does John like X?

```
?- likes(john, X) .
```

or

```
?- likes(john, SomethingThatJohnLikes) .
```

X and SomethingThatJohnLikes are variables.

Variable begins with a capital letter.



# PROLOG Answer

**Database:**

```
likes(john, flowers) .
```

**Question:**

```
?- likes(john, X) .
```

**PROLOG answers:**

```
X=flowers
```

# Many Answers

## Database:

likes(john,flowers).

likes(john,mary).

likes(paul,mary).

## Question:

?- likes(john,X).

## PROLOG answers:

X=flowers

and the user acknowledges

X=mary

and the user acknowledges

no

# Placemark

- ▶ The first match is found: `X=flowers`.
- ▶ The user acknowledges.
- ▶ From that place on the next match is found (the search continues).
- ▶ From the place of the last instantiation no more match was found.
- ▶ Thus answer: `no`.

# Conjunctions

More Complicated Relationships:

Does Mary like John and does John like Mary?

Both Conditions must be fulfilled.

# Conjunctions

Comma means Conjunction:

?- likes(john,mary), likes(mary, john) .

likes(mary, food) .

likes(mary, wine) .

likes(john, wine) .

likes(john, mary) .

Answer: no

A match for likes(john, mary)

but none for likes(mary, john)

# Conjunctions with Variables

Is there anything that both mary and john like?

Find out what Mary likes and then see if John likes it.

```
?- likes(mary,X), likes(john,X).
```

# Backtracking

- ▶ Find match for the first goal.
- ▶ Then see if matches the second.
- ▶ If not, find another match for the first.
- ▶ See if this matches the second.
- ▶ etc.

# Match First

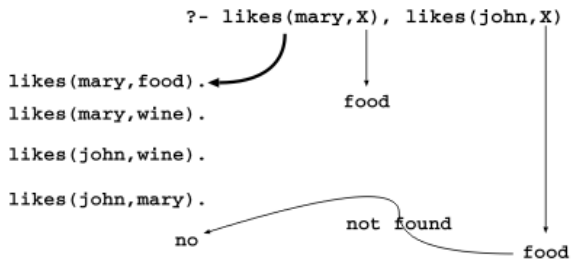
```
?- likes(mary,X), likes(john,X)
```

likes(mary,food).  
likes(mary,wine).  
likes(john,wine).  
likes(john,mary).

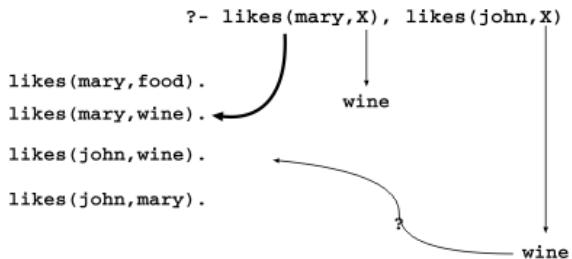
The diagram illustrates the variable binding process for the query `?- likes(mary,X), likes(john,X)`. It shows four facts in the knowledge base: `likes(mary,food).`, `likes(mary,wine).`, `likes(john,wine).`, and `likes(john,mary).`. Arrows indicate the binding of the variable `X` in the query to the values in the facts. The first arrow points from `X` in the first clause of the query to `food` in the first fact. The second arrow points from `X` in the second clause of the query to `wine` in the third fact. The word `food` appears below the query and the first fact, and `wine` appears below the third fact, indicating the values that satisfy the query.



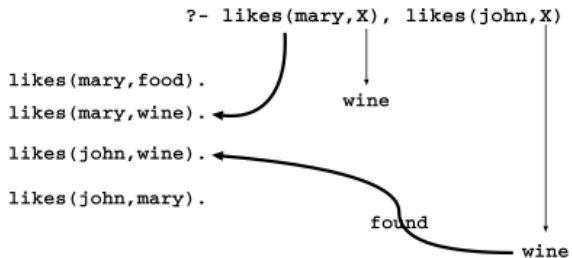
# Match Second



# Backtrack



# Success



# Rules

- ▶ How to express that John likes all people?

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  - ▶ `likes(john,alfred).`
  - ▶ `likes(john,bertrand).`
  - ▶ `likes(john,charles).`



# Rules

- ▶ How to express that John likes all people?
- ▶ Listing all people?
  - ▶ `likes(john,alfred).`
  - ▶ `likes(john,bertrand).`
  - ▶ `likes(john,charles).`
  - ▶ `likes(john,david).`
  - ▶ **etc.**

# Rules

- ▶ How to express that John likes all people?
- ▶ Listing all people?
  - ▶ `likes(john,alfred) .`
  - ▶ `likes(john,bertrand) .`
  - ▶ `likes(john,charles) .`
  - ▶ `likes(john,david) .`
  - ▶ `etc.`
- ▶ Not feasible. More compact way: Using **rules**.  
John likes any object provided it is a person.

# Rule Examples

- ▶ Rules state Dependence:  
I use an umbrella **if** there is rain.

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- ▶ Rules state Dependence:  
I use an umbrella **if** there is rain.
- ▶ Rules Define:  
X is a bird **if** X is an animal and X has feathers.

# Formulating Rules

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- ▶ John likes anyone who likes wine.
- ▶ John likes any something if it likes wine.
- ▶ John likes X if X likes wine.

# Rule Syntax

$\underbrace{\text{likes}(\text{john}, X)}_{\text{head}} \text{ :- } \underbrace{\text{likes}(X, \text{wine})}_{\text{body}}.$

rule delimiter

The diagram illustrates the syntax of a Prolog rule. The rule is written as `likes(john, X) :- likes(X, wine).`. The text `likes(john, X)` is underlined with a bracket and labeled "head". The text `likes(X, wine)` is underlined with a bracket and labeled "body". The text `:-` is labeled "rule delimiter" with an arrow pointing to it. The period `.` is not explicitly labeled but is part of the rule's structure.



# Variable Scope

The occurrences of  $x$  within a rule:

```
likes(john, X) :- likes(X, wine),  
                 likes(X, food) .
```

# Variable Scope

The occurrences of  $x$  within a rule:

instantiates here  
↓

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# Variable Scope

The occurrences of  $x$  within a rule:

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                  likes (X, food) .
```

↑

checked here

# Variable Scope

The occurrences of `x` within a rule:

```
likes (john, X) :- likes (X, wine),  
likes (X, food) .
```

↑ returns here

instantiates here  
↓

↑ checked here

# Royal Parents

## Example

- ▶ The parents of X are Y and Z.
- ▶ Y is the mother.
- ▶ Z is the father.

## Database:

```
male(albert) .  
male(edward) .  
female(alice) .  
female(victoria) .  
parents(edward,victoria,albert) .  
parents(alice,victoria,albert) .
```

# Sisters

## Example

X is a sister of Y if:

# Sisters

## Example

X is a sister of Y if:

- ▶ X is female,

# Sisters

## Example

X is a sister of Y if:

- ▶ X is female,
- ▶ X has parents M and F,



# Sisters

## Example

X is a sister of Y if:

- ▶ X is female,
- ▶ X has parents M and F,
- ▶ Y has parents M and F.

# Sisters

## Example

X is a sister of Y if:

- ▶ X is female,
- ▶ X has parents M and F,
- ▶ Y has parents M and F.

Rule:

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

# Sisters Question

## Rule:

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

## Question:

```
sister(alice,edward).
```

# Sisters Question

## Rule:

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sister(X,Y) :- female(X),  
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- ▶ The question (goal) matches the head of the rule, if one replaces `X` with `alice` and `Y` with `edward`.

# Sisters Question

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

## Question:

```
sister(alice,edward).
```

- ▶ The question (goal) matches the head of the rule, if one replaces `X` with `alice` and `Y` with `edward`.
- ▶ The instance of the body becomes new goal:

```
female(alice),  
parents(alice,M,F),  
parents(edward,M,F).
```

# Is Alice Edward's Sister?

```
sister(alice,edward)
```

- (1) male(albert).
- (2) male(edward).
- (3) female(alice).
- (4) female(victoria).
- (5) parents(edward,  
victoria,  
albert).
- (6) parents(alice,  
victoria,  
albert).
- (7) sister(X,Y):-  
female(X),  
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    `albert).`
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    `victoria,`  
    `albert).`
- (7) **`sister(X0,Y0):-`**  
    **`female(X0),`**  
    **`parents(X0,M0,F0),`**  
    **`parents(Y0,M0,F0).`**

**`sister(alice,edward)`**

↓  
X0=alice,  
Y0=edward

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    |
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  parents(edward,M0,F0).
    |
    | M0=victoria,
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7 `sister(alice,edward)`

↓ `X0=alice,  
Y0=edward`

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parents(alice,M0,F0),  
parents(edward,M0,F0).`

↓

6 `parents(alice,M0,F0),  
parents(edward,M0,F0).`

↓ `M0=victoria,  
F0=albert`

**`parents(edward,victoria,albert).`**

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(2) male(edward).
(3) female(alice).
(4) female(victoria).
(5) parents(edward,
            victoria,
            albert).
(6) parents(alice,
            victoria,
            albert).
(7) sister(X,Y):-
    female(X),
    parents(X,M,F),
    parents(Y,M,F).
```

```
7 sister(alice,edward)
    | X0=alice,
    | Y0=edward
    |
    v
3 female(alice),
  parents(alice,M0,F0),
  parents(edward,M0,F0).
    |
    v
6 parents(alice,M0,F0),
  parents(edward,M0,F0).
    |
    | M0=victoria,
    | F0=albert
    |
    v
5 parents(edward,victoria,albert).
    |
    v
```

# Is Alice Edward's Sister?

```
(1) male(albert).
(2) male(edward).
(3) female(alice).
(4) female(victoria).
(5) parents(edward,
            victoria,
            albert).
(6) parents(alice,
            victoria,
            albert).
(7) sister(X,Y):-
    female(X),
    parents(X,M,F),
    parents(Y,M,F).
```

```
7 sister(alice,edward)
    | X0=alice,
    | Y0=edward
    |
    v
3 female(alice),
  parents(alice,M0,F0),
  parents(edward,M0,F0).
    |
    v
6 parents(alice,M0,F0),
  parents(edward,M0,F0).
    |
    | M0=victoria,
    | F0=albert
    |
    v
5 parents(edward,victoria,albert).
    |
    v
    ■
```

# Who's Sister Is Alice?

```
sister(alice,X)
```

- (1) male(albert).
- (2) male(edward).
- (3) female(alice).
- (4) female(victoria).
- (5) parents(edward,  
victoria,  
albert).
- (6) parents(alice,  
victoria,  
albert).
- (7) sister(X,Y):-  
female(X),  
parents(X,M,F),  
parents(Y,M,F).

# Who's Sister Is Alice?

**sister(alice,X)**

- (1) male(albert).
- (2) male(edward).
- (3) female(alice).
- (4) female(victoria).
- (5) parents(edward,  
    victoria,  
    albert).
- (6) parents(alice,  
    victoria,  
    albert).
- (7) sister(X,Y):-  
    female(X),  
    parents(X,M,F),  
    parents(Y,M,F).



# Who's Sister Is Alice?

**sister(alice,X)**

- (1) male(albert).
- (2) male(edward).
- (3) female(alice).
- (4) female(victoria).
- (5) parents(edward,  
victoria,  
albert).
- (6) parents(alice,  
victoria,  
albert).
- (7) **sister(X,Y):-**  
female(X),  
parents(X,M,F),  
parents(Y,M,F).

# Who's Sister Is Alice?

**sister(alice,X)**

- (1) male(albert).
- (2) male(edward).
- (3) female(alice).
- (4) female(victoria).
- (5) parents(edward,  
victoria,  
albert).
- (6) parents(alice,  
victoria,  
albert).
- (7) **sister(X0,Y0):-**  
female(X0),  
parents(X0,M0,F0),  
parents(Y0,M0,F0).

# Who's Sister Is Alice?

- (1) `male(albert).`
- (2) `male(edward).`
- (3) `female(alice).`
- (4) `female(victoria).`
- (5) `parents(edward,`  
    `victoria,`  
    `albert).`
- (6) `parents(alice,`  
    `victoria,`  
    `albert).`
- (7) **`sister(X0,Y0):-`**  
    **`female(X0),`**  
    **`parents(X0,M0,F0),`**  
    **`parents(Y0,M0,F0).`**

**sister(alice,X)**

↓  $X0=alice,$   
    $Y0=X$

# Who's Sister Is Alice?

- (1) male(albert).
- (2) male(edward).
- (3) female(alice).
- (4) female(victoria).
- (5) parents(edward,  
victoria,  
albert).
- (6) parents(alice,  
victoria,  
albert).
- (7) sister(X0,Y0):-  
    **female(X0),**  
    **parents(X0,M0,F0),**  
    **parents(Y0,M0,F0).**

7 sister(alice,X)

↓ X0=alice,  
   Y0=X

female(alice),  
parents(alice,M0,F0),  
parents(X,M0,F0).

# Who's Sister Is Alice?

- (1) `male(albert).`
- (2) `male(edward).`
- (3) `female(alice).`
- (4) `female(victoria).`
- (5) `parents(edward,  
victoria,  
albert).`
- (6) `parents(alice,  
victoria,  
albert).`
- (7) `sister(X,Y):-  
female(X),  
parents(X,M,F),  
parents(Y,M,F).`

7 `sister(alice,X)`

↓ `X0=alice,  
Y0=X`

**female(alice),**  
`parents(alice,M0,F0),`  
`parents(X,M0,F0).`

# Who's Sister Is Alice?

- (1) `male(albert).`
- (2) `male(edward).`
- (3) **`female(alice).`**
- (4) `female(victoria).`
- (5) `parents(edward,  
victoria,  
albert).`
- (6) `parents(alice,  
victoria,  
albert).`
- (7) `sister(X,Y):-  
female(X),  
parents(X,M,F),  
parents(Y,M,F).`

7 `sister(alice,X)`

↓ `X0=alice,  
Y0=X`

**`female(alice),`**  
`parents(alice,M0,F0),`  
`parents(X,M0,F0).`

# Who's Sister Is Alice?

- (1) `male(albert).`
- (2) `male(edward).`
- (3) **`female(alice).`**
- (4) `female(victoria).`
- (5) `parents(edward,  
victoria,  
albert).`
- (6) `parents(alice,  
victoria,  
albert).`
- (7) `sister(X,Y):-  
female(X),  
parents(X,M,F),  
parents(Y,M,F).`

```
7 sister(alice,X)
      ↓
      X0=alice,
      Y0=X
female(alice),
parents(alice,M0,F0),
parents(X,M0,F0).
      ↓
```

# Who's Sister Is Alice?

```
(1) male(albert).
(2) male(edward).
(3) female(alice).
(4) female(victoria).
(5) parents(edward,
            victoria,
            albert).
(6) parents(alice,
            victoria,
            albert).
(7) sister(X,Y):-
    female(X),
    parents(X,M,F),
    parents(Y,M,F).
```

```
7 sister(alice,X)
      ↓
      X0=alice,
      Y0=X
3 female(alice),
  parents(alice,M0,F0),
  parents(X,M0,F0).
      ↓
parents(alice,M0,F0),
parents(X,M0,F0).
```



# Who's Sister Is Alice?

```
(1) male(albert).
(2) male(edward).
(3) female(alice).
(4) female(victoria).
(5) parents(edward,
            victoria,
            albert).
(6) parents(alice,
            victoria,
            albert).
(7) sister(X,Y):-
    female(X),
    parents(X,M,F),
    parents(Y,M,F).
```

```
7 sister(alice,X)
      ↓
      X0=alice,
      Y0=X
3 female(alice),
  parents(alice,M0,F0),
  parents(X,M0,F0).
      ↓
parents(alice,M0,F0),
  parents(X,M0,F0).
```

# Who's Sister Is Alice?

- (1) male(albert).
- (2) male(edward).
- (3) female(alice).
- (4) female(victoria).
- (5) parents(edward,  
victoria,  
albert).
- (6) **parents(alice,  
victoria,  
albert).**
- (7) sister(X,Y):-  
female(X),  
parents(X,M,F),  
parents(Y,M,F).

```
7 sister(alice,X)
      ↓
      X0=alice,
      Y0=X
3 female(alice),
  parents(alice,M0,F0),
  parents(X,M0,F0).
      ↓
parents(alice,M0,F0),
  parents(X,M0,F0).
```

# Who's Sister Is Alice?

- (1) `male(albert).`
- (2) `male(edward).`
- (3) `female(alice).`
- (4) `female(victoria).`
- (5) `parents(edward,  
victoria,  
albert).`
- (6) **`parents(alice,  
victoria,  
albert).`**
- (7) `sister(X,Y):-  
female(X),  
parents(X,M,F),  
parents(Y,M,F).`

```
7 sister(alice,X)
    ↓
  X0=alice,
  Y0=X
3 female(alice),
  parents(alice,M0,F0),
  parents(X,M0,F0).
    ↓
parents(alice,M0,F0),
  parents(X,M0,F0).
    ↓
  M0=victoria
  F0=albert
```

# Who's Sister Is Alice?

```
(1) male(albert).
(2) male(edward).
(3) female(alice).
(4) female(victoria).
(5) parents(edward,
            victoria,
            albert).
(6) parents(alice,
            victoria,
            albert).
(7) sister(X,Y):-
    female(X),
    parents(X,M,F),
    parents(Y,M,F).
```

```
7 sister(alice,X)
    ↓
  X0=alice,
  Y0=X
3 female(alice),
  parents(alice,M0,F0),
  parents(X,M0,F0).
    ↓
6 parents(alice,M0,F0),
  parents(X,M0,F0).
    ↓
  M0=victoria
  F0=albert
parents(X,victoria,albert).
```

# Who's Sister Is Alice?

```
(1) male(albert).
(2) male(edward).
(3) female(alice).
(4) female(victoria).
(5) parents(edward,
    victoria,
    albert).
(6) parents(alice,
    victoria,
    albert).
(7) sister(X,Y):-
    female(X),
    parents(X,M,F),
    parents(Y,M,F).
```

```
7 sister(alice,X)
    ↓
    X0=alice,
    Y0=X
3 female(alice),
  parents(alice,M0,F0),
  parents(X,M0,F0).
    ↓
6 parents(alice,M0,F0),
  parents(X,M0,F0).
    ↓
    M0=victoria
    F0=albert
parents(X,victoria,albert).
```

# Who's Sister Is Alice?

```
(1) male(albert).
(2) male(edward).
(3) female(alice).
(4) female(victoria).
(5) parents(edward,
            victoria,
            albert).
(6) parents(alice,
            victoria,
            albert).
(7) sister(X,Y):-
    female(X),
    parents(X,M,F),
    parents(Y,M,F).
```

```
7 sister(alice,X)
    ↓
   X0=alice,
   Y0=X
3 female(alice),
  parents(alice,M0,F0),
  parents(X,M0,F0).
    ↓
6 parents(alice,M0,F0),
  parents(X,M0,F0).
    ↓
   M0=victoria
   F0=albert
5 parents(X,victoria,albert).
    ↓
   X=edward
```

# Who's Sister Is Alice?

```
(1) male(albert).
(2) male(edward).
(3) female(alice).
(4) female(victoria).
(5) parents(edward,
            victoria,
            albert).
(6) parents(alice,
            victoria,
            albert).
(7) sister(X,Y):-
    female(X),
    parents(X,M,F),
    parents(Y,M,F).
```

```
7 sister(alice,X)
    ↓
  X0=alice,
  Y0=X
3 female(alice),
  parents(alice,M0,F0),
  parents(X,M0,F0).
    ↓
6 parents(alice,M0,F0),
  parents(X,M0,F0).
    ↓
  M0=victoria
  F0=albert
5 parents(X,victoria,albert).
    ↓
  X=edward
  ■
```

Answer: X = edward.

# Stealing

- ▶ The Rule:

A person may steal something if the person is a thief and he likes the thing.

- ▶ Prolog Rule:

```
may_steal(P, T) :- thief(P), likes(P, T) .
```



# Stealing

## Example (thief.pl)

```
thief(john).  
likes(mary, food).  
likes(mary, wine).  
likes(john, X) :- likes(X, wine).  
may_steal(X, Y) :- thief(X), likes(X, Y).
```

## Demo thief.pl.

▶ ?- may\_steal(john, X).