Programming Paradigms

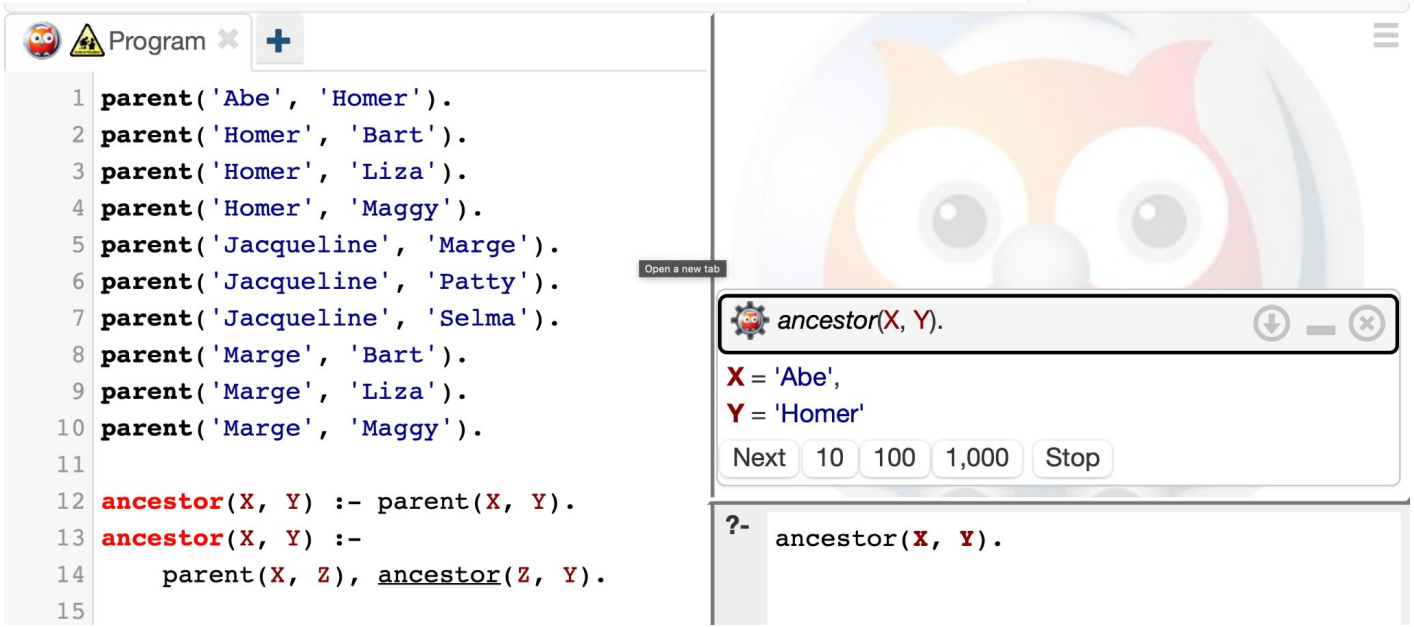
Lecture 10. Introduction to Prolog

Outline

- Recapping Prolog syntax
- Unification
- Proof search
- Recursion

Some Prolog-like programming languages

Development environment



https://swish.swi-prolog.org

Syntax: simple facts

```
person(mia).
person(jack).
person(yolanda).

likes(vincent, mia).
likes(marsellus, mia).
likes(pumpkin, honey_bunny).
likes(honey_bunny, pumpkin).
```

Syntax: clauses and arity

```
parent('Abe', 'Homer').
parent('Homer', 'Bart').
parent('Homer', 'Liza').
parent('Homer', 'Maggy').
```

Syntax: clauses and arity

```
parent('Abe', 'Homer').
parent('Homer', 'Bart').
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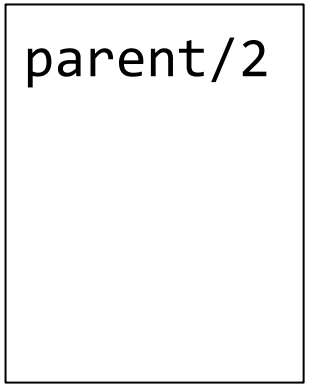
```

parent/2

Syntax: clauses and arity

```
parent('Abe', 'Homer').
parent('Homer', 'Bart').
parent('Homer', 'Liza').
parent('Homer', 'Maggy').

male('Abe').
male('Homer').
male('Bart').
```



Syntax: clauses and arity

```
parent('Abe', 'Homer').
parent('Homer', 'Bart').
parent('Homer', 'Liza').
parent('Homer', 'Maggy').

male('Abe').
male('Homer').
male('Bart').
```

```
parent/2

male/1
```

Syntax: clauses and arity

```
parent('Abe', 'Homer').
parent('Homer', 'Bart').
parent('Homer', 'Liza').
parent('Homer', 'Maggy').

male('Abe').
male('Homer').
male('Bart').

father('Homer') :- male('Homer'), parent('Homer').
```

```
parent/2

male/1
```

Syntax: clauses and arity

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parent('Abe', 'Homer').
parent('Homer', 'Bart').
parent('Homer', 'Liza').
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male('Abe').
male('Homer').
male('Bart').

father('Homer') :- male('Homer'), parent('Homer').
```

```
parent/2

male/1

father/1
```

Syntax: atoms, variables and numbers

1. Atoms — start with lowercase letter, or put in single quotes
   `jack, 'Homer', somethingElse_123`

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   `X, Y, Homer, Parent, Child, _G123, _`

Syntax: atoms, variables and numbers

1. Atoms — start with lowercase letter, or put in single quotes
   `jack, 'Homer', somethingElse_123`

2. Variables — start with underscore or uppercase letter
   `X, Y, Homer, Parent, Child, _G123, _`

3. Numbers — as usual,
   but we are interested only in integers most of the time
   `12, -5, 0`

Syntax: complex terms

```
functor(term1, term2, ..., termN)
```

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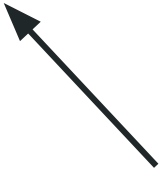

Only atom, cannot be a variable!

Syntax: complex terms

```
functor(term1, term2, ..., termN)
```

```
parent(jack, anne)
```

Syntax: complex terms

```
functor(term1, term2, ..., termN)
```

```
parent(jack, anne)
add(1, 2)
```

Syntax: complex terms

```
functor(term1, term2, ..., termN)
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```
parent(jack, anne)
add(1, 2)
add(1, add(3, 4))
```

Syntax: complex terms

```
functor(term1, term2, ..., termN)
```

```
parent(jack, anne)
add(1, 2)
add(1, add(3, 4))
add(X, add(3, Y))
```

Syntax: complex terms

```
functor(term1, term2, ..., termN)


parent(jack, anne)
add(1, 2)
add(1, add(3, 4))
add(X, add(3, Y))

X(jack)
```

Syntax: complex terms

```
functor(term1, term2, ..., termN)
```

```
parent(jack, anne)
add(1, 2)
add(1, add(3, 4))
add(X, add(3, Y))
```

`X(jack)` — not a valid term

Unification

Consider the three groups of terms:

1. Constants (atoms, numbers) — `hello, 23, 'a book'`
2. Variables — `X, Book, _Example, _`
3. Complex terms — `connected(1, Y), parent('Homer')`

Unification

Consider the three groups of terms:

1. Constants (atoms, numbers) — `hello, 23, 'a book'`
2. Variables — `X, Book, _Example, _`
3. Complex terms — `connected(1, Y), parent('Homer')`

Intuitively, two terms unify

1. if they are the same, or
2. if variables in both terms can be instantiated to make the terms the same

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```
?- hello = hello
```

Unification

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```
?- hello = hello
```

true

Unification

Intuitively, two terms unify

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```
?- 42 = 42
```

Unification

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2. if variables in both terms can be instantiated to make the terms the same

```
?- 42 = 42
```

true

Unification

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```
?- 42 = 21+21
```

Unification

Intuitively, two terms unify

1. if they are the same, or
2. if variables in both terms can be instantiated to make the terms the same

```
?- 42 = 21+21
```

false

Unification

Intuitively, two terms unify

1. if they are the same, or
2. if variables in both terms can be instantiated to make the terms the same

```
?- hello = X
```

Unification

Intuitively, two terms unify

1. if they are the same, or
2. if variables in both terms can be instantiated to make the terms the same

```
?- hello = X
```

X = hello

Unification

Intuitively, two terms unify

1. if they are the same, or
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```
?- word(hello) = word(X)
```

Unification

Intuitively, two terms unify

1. if they are the same, or
2. if variables in both terms can be instantiated to make the terms the same

```
?- word(hello) = word(X)
```

X = hello

Unification

Intuitively, two terms unify

1. if they are the same, or
2. if variables in both terms can be instantiated to make the terms the same

```
?- word(hello) = X
```

Unification

Intuitively, two terms unify

1. if they are the same, or
2. if variables in both terms can be instantiated to make the terms the same

```
?- word(hello) = X

X = word(hello)
```

Unification

Intuitively, two terms unify

1. if they are the same, or
2. if variables in both terms can be instantiated to make the terms the same

```
?- parent(X, 'Bart') = parent('Homer', Y)
```

Unification

Intuitively, two terms unify

1. if they are the same, or
2. if variables in both terms can be instantiated to make the terms the same

```
?- parent(X, 'Bart') = parent('Homer', Y)
```

```
X = 'Homer',
Y = 'Bart'
```

Unification

Intuitively, two terms unify

1. if they are the same, or
2. if variables in both terms can be instantiated to make the terms the same

```
?- parent(X, 'Bart') = parent('Homer', X)
```

Unification

Intuitively, two terms unify

1. if they are the same, or
2. if variables in both terms can be instantiated to make the terms the same

```
?- parent(X, 'Bart') = parent('Homer', X)
```

false

Does **not** unify!

Unification

Intuitively, two terms unify

1. if they are the same, or
2. if variables in both terms can be instantiated to make the terms the same

```
?- friend(X, 'Bart') = friend('Bart', X)
```

Unification

Intuitively, two terms unify

1. if they are the same, or
2. if variables in both terms can be instantiated to make the terms the same

```
?- friend(X, 'Bart') = friend('Bart', X)

X = 'Bart'
```

Proof search

```
?- musicalChild(X)
```

```
human('Bart').
human('Liza').

child('Bart').
child('Liza').

playsSax('Liza').

musicalChild(X) :- human(X), child(X), playsSax(X).
```

Proof search

```
?- m(X)
```

```
h(b).
h(l).

c(b).
c(l).

p(l).

m(X) :- h(X), c(X), p(X).
```

Proof search

```
?- m(X)
```

```
h(b).
h(l).

c(b).
c(l).

p(l).

m(X) :- h(X), c(X), p(X).
```

Proof search

```
?- m(X)
```

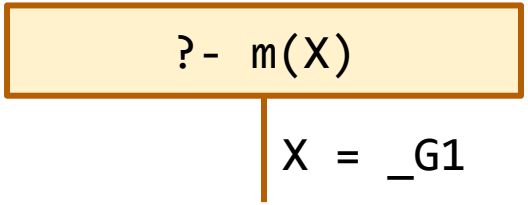
```
h(b).
h(l).

c(b).
c(l).

p(l).

m(_G1) :- h(_G1), c(_G1), p(_G1).
```

Proof search




```
h(b).
h(l).

c(b).
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p(l).

m(X) :- h(X), c(X), p(X).
```

Proof search

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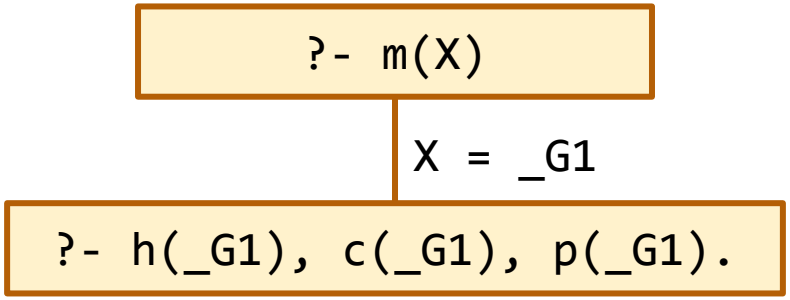

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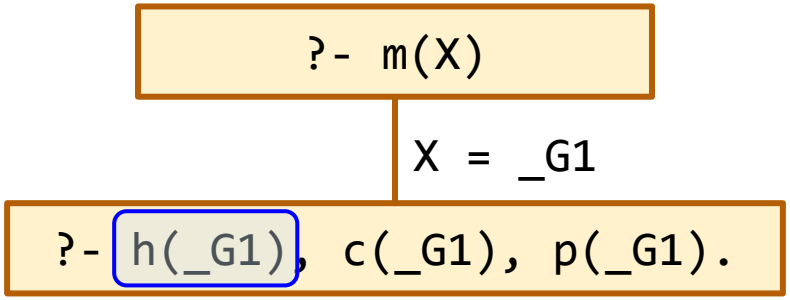

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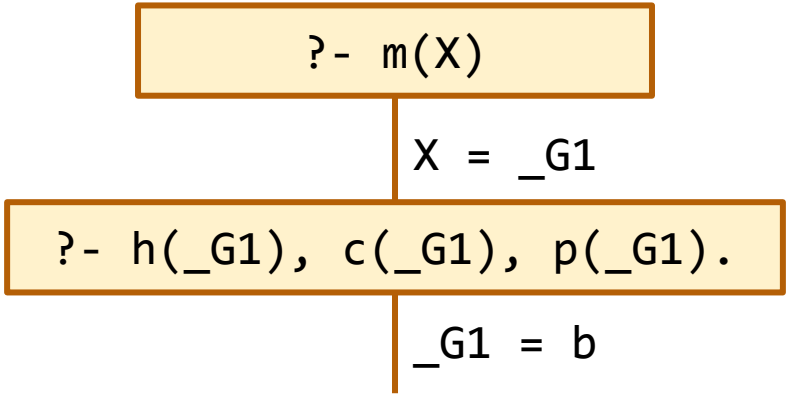

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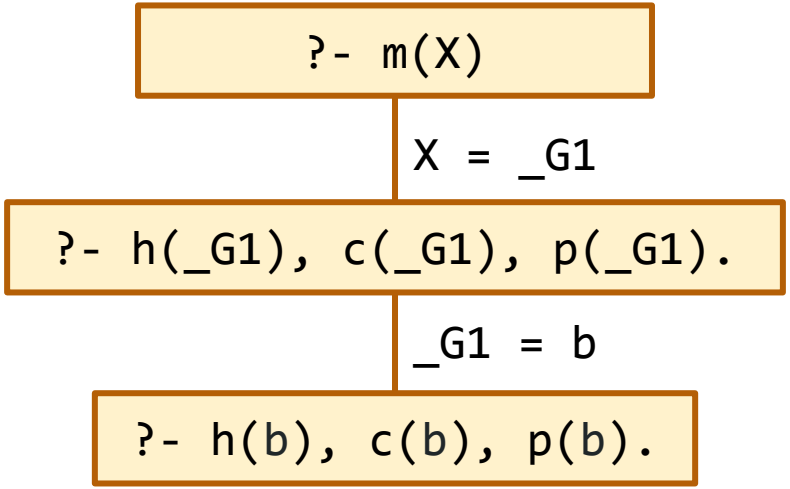

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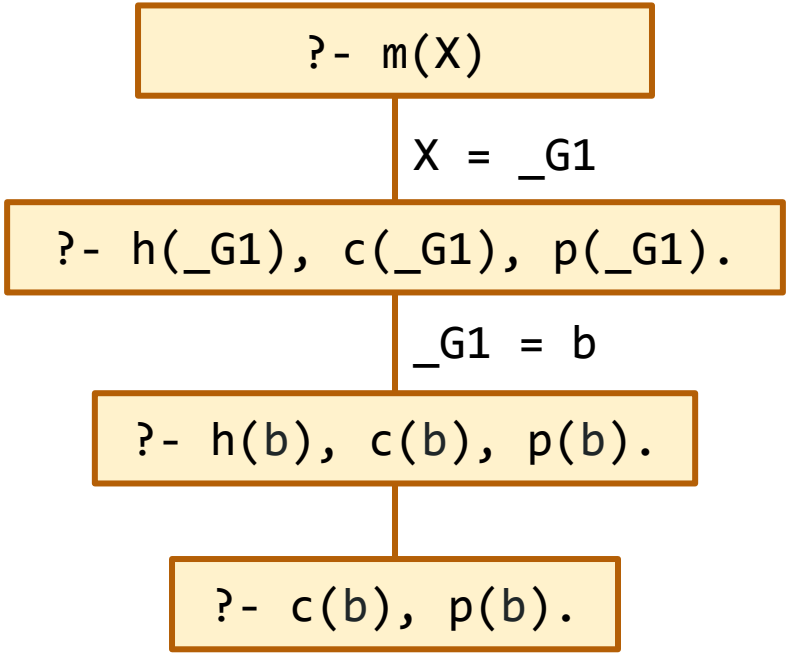

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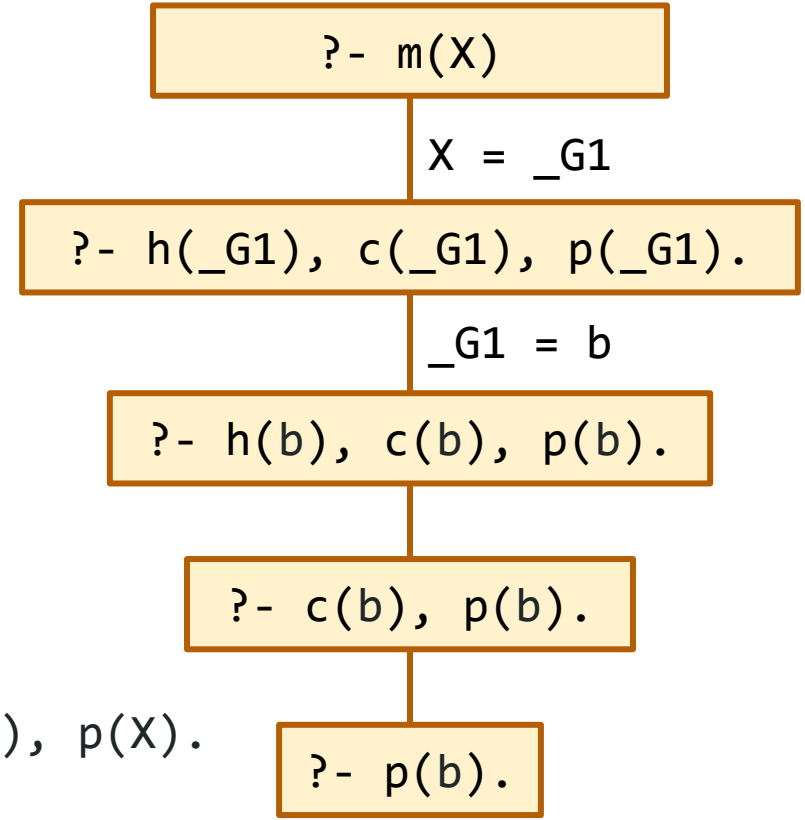

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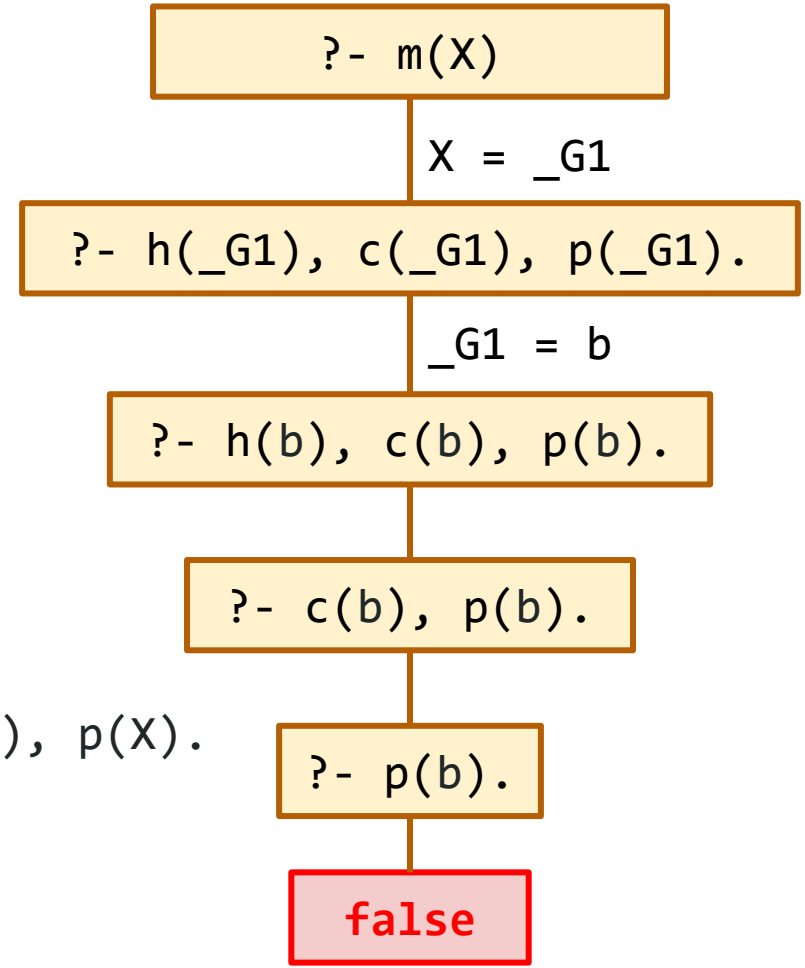

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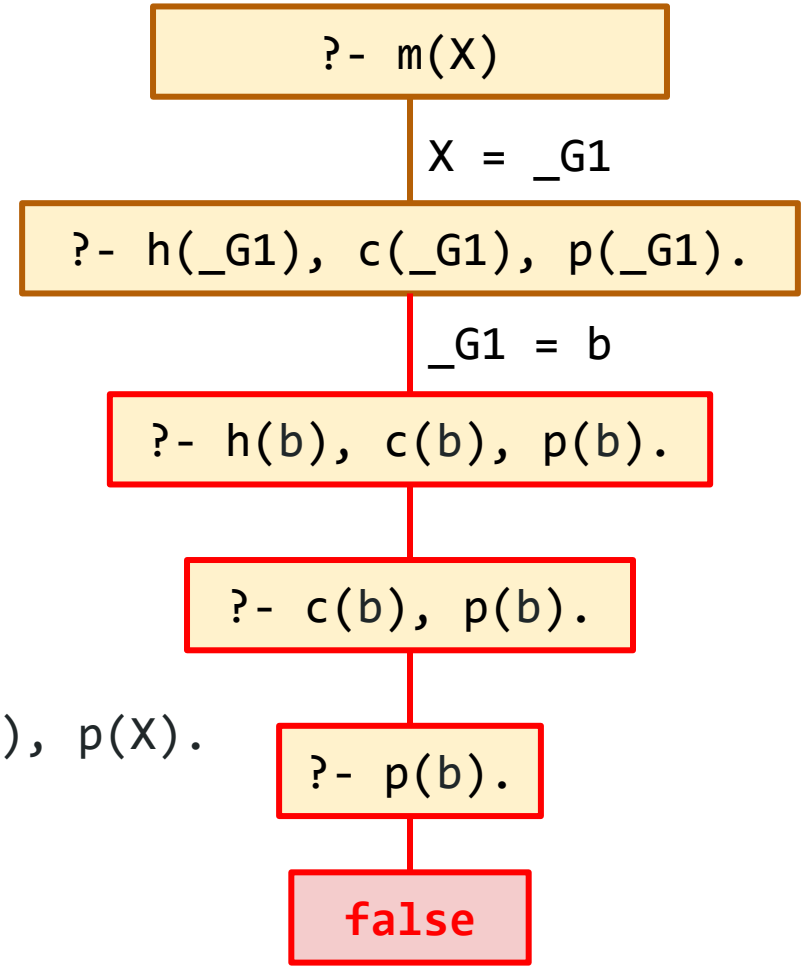

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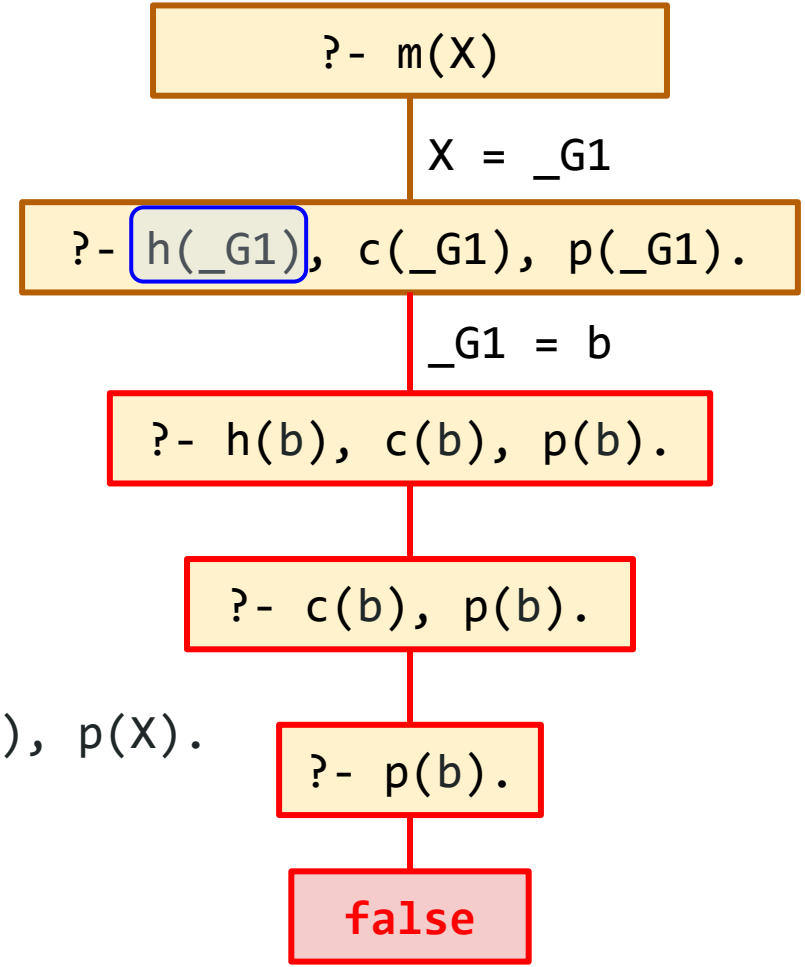

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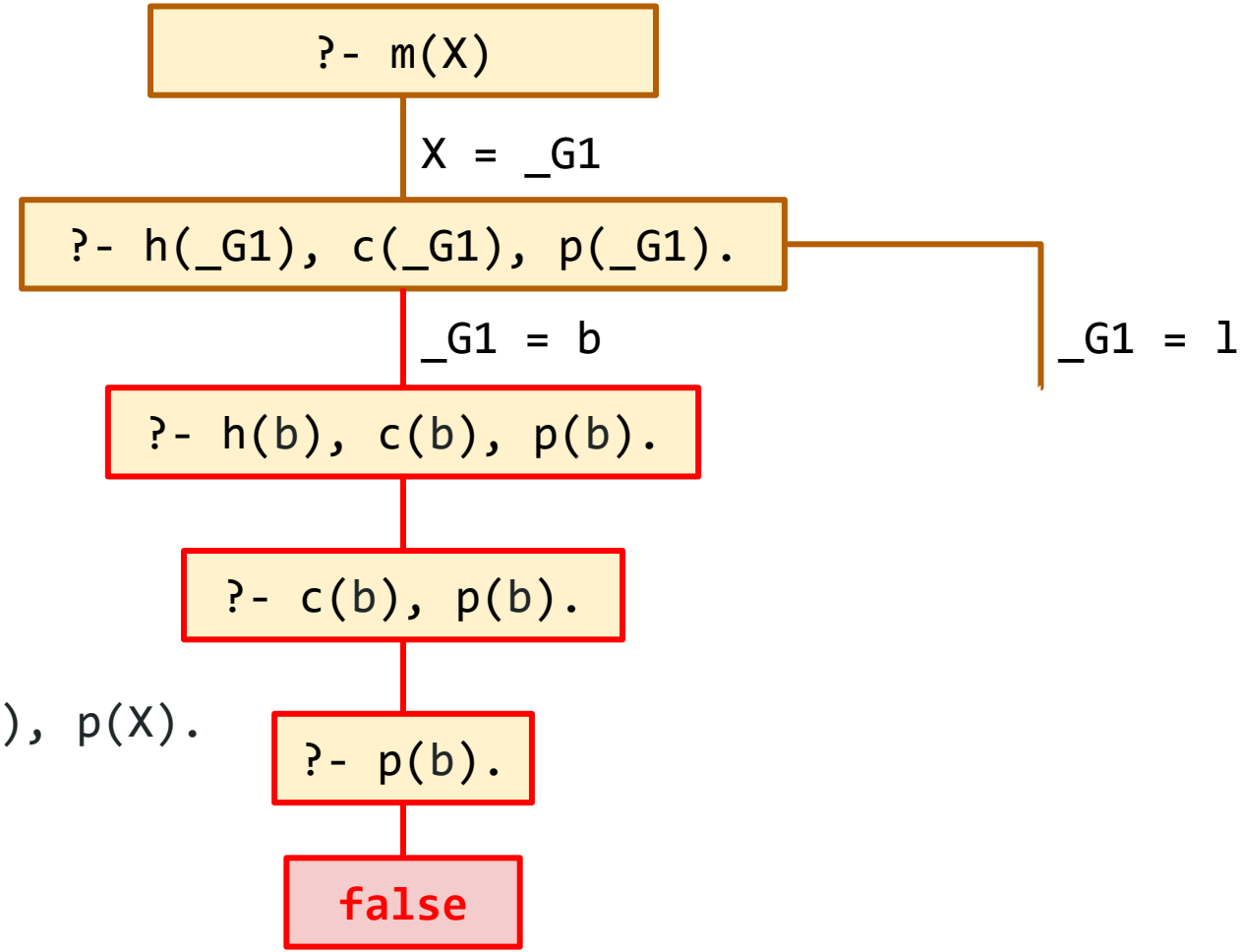

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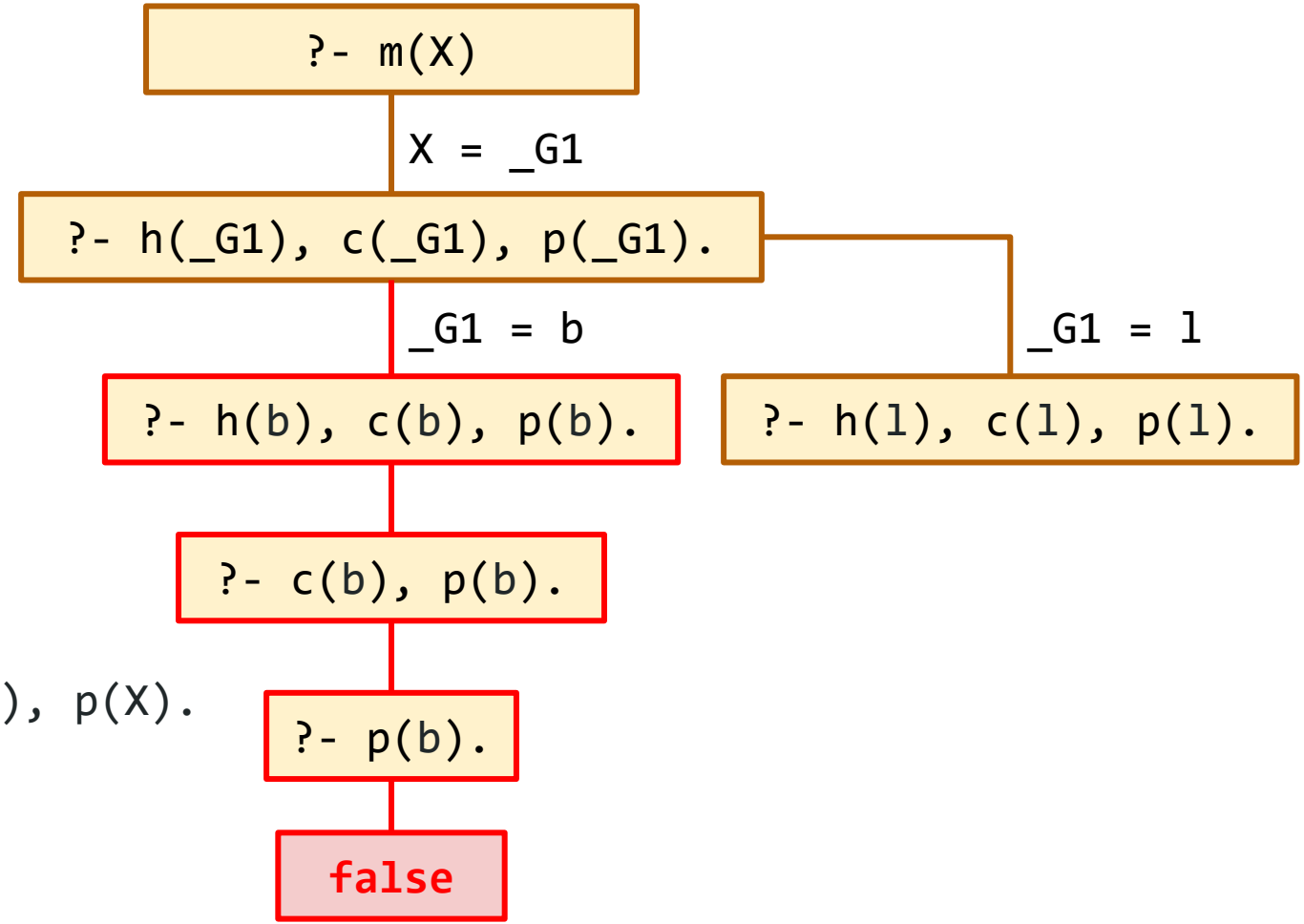

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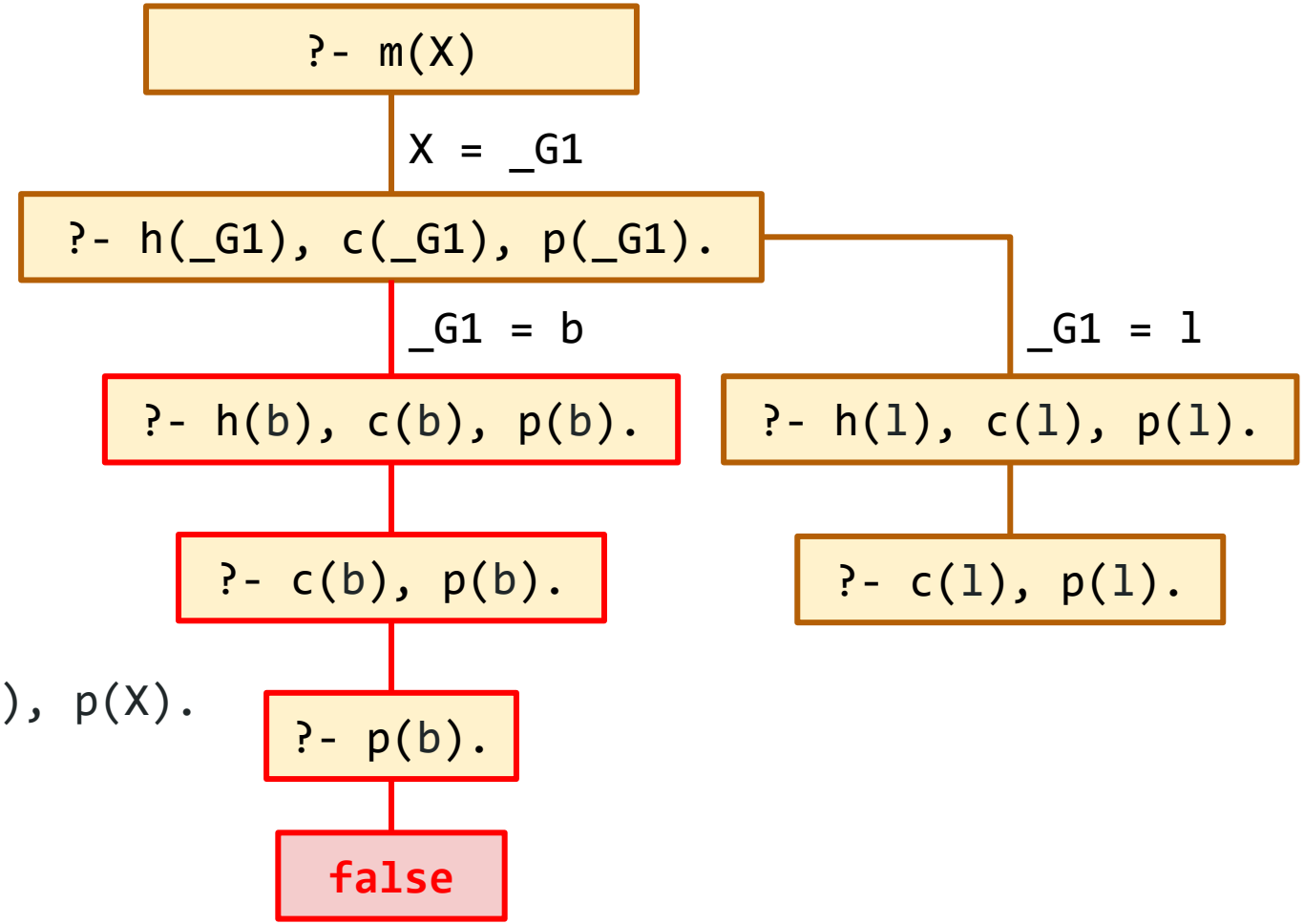

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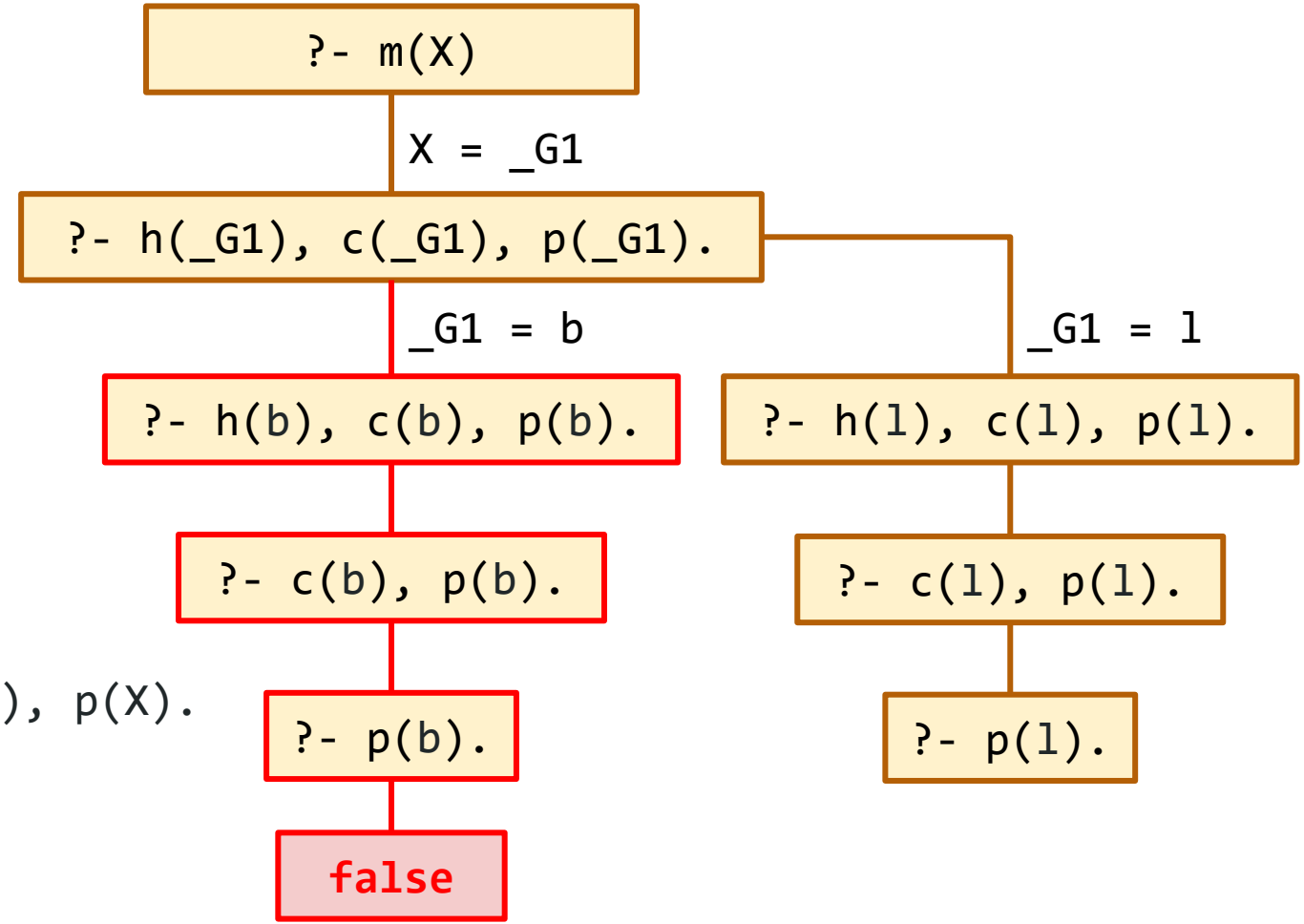

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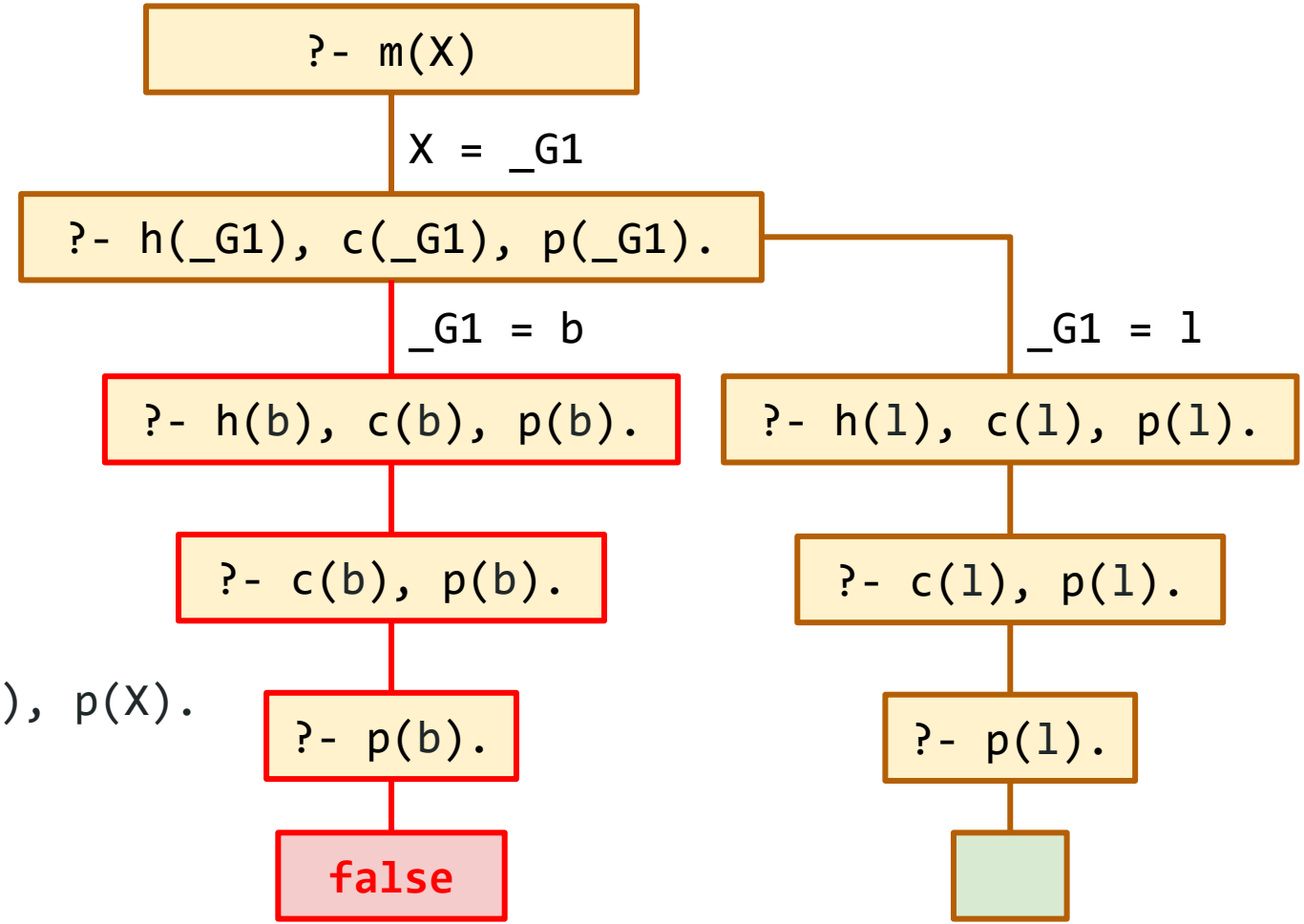

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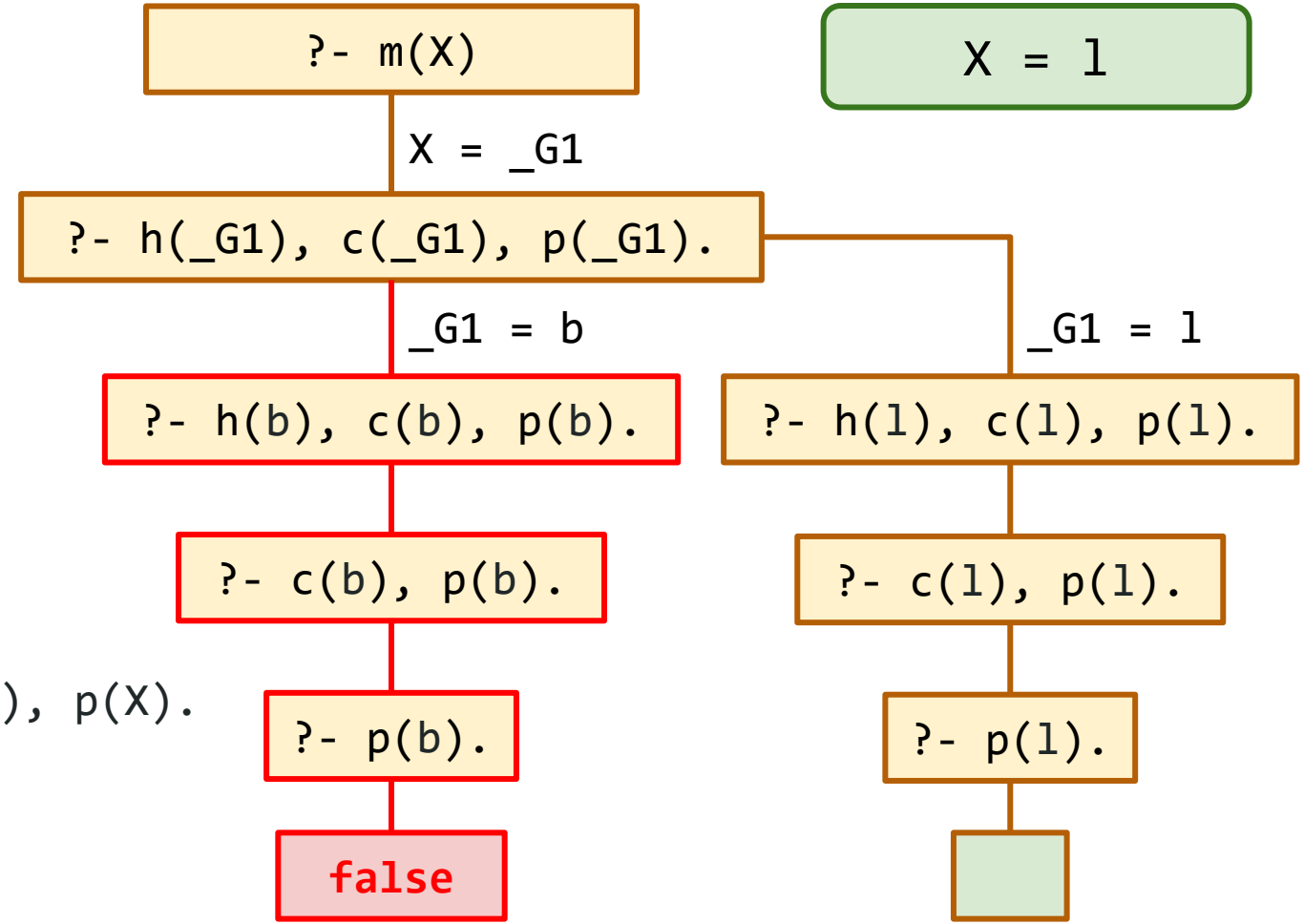


Proof search: example 2

```
?- sibling(X, Y)
```

```
parent(a, b).
parent(a, c).

sibling(X, Y) :- parent(P, X), parent(P, Y).
```

Question: Is there a valid answer? Is yes, then how many?

Proof search: example 2

```
?- s(X, Y)
```

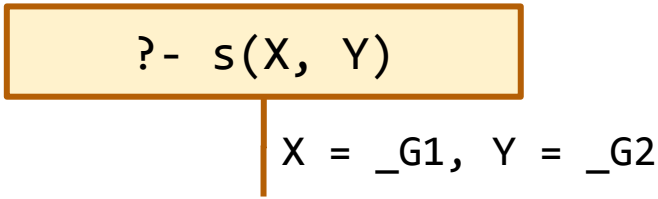
```
p(a, b).
p(a, c).

s(X, Y) :- p(P, X), p(P, Y).
```

Proof search: example 2

```
p(a, b).
p(a, c).

s(X, Y) :- p(P, X), p(P, Y).
```



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s(X, Y) :- p(P, X), p(P, Y).
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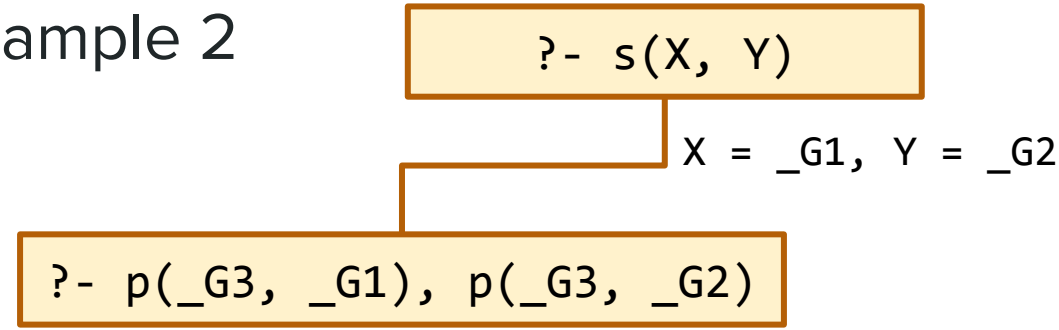

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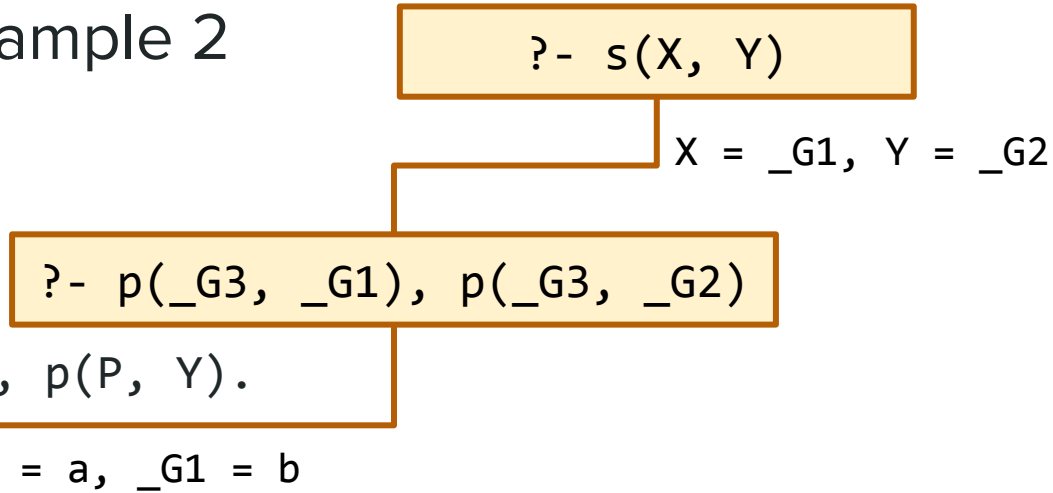

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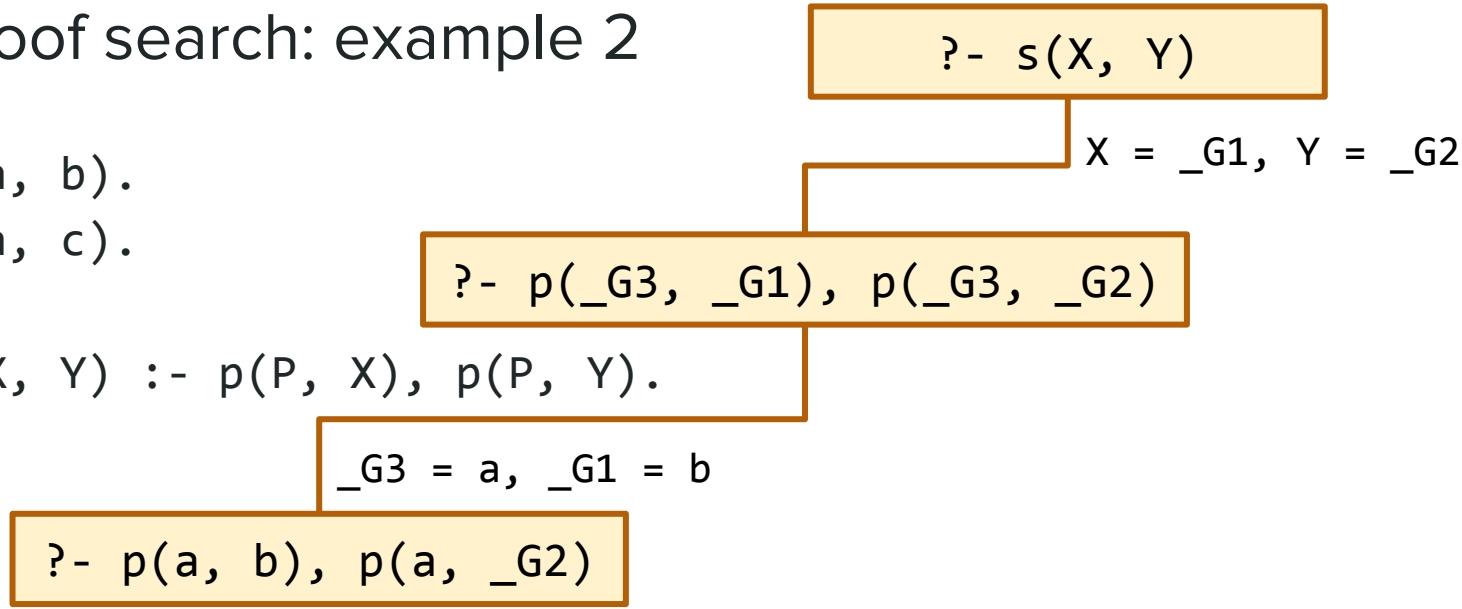

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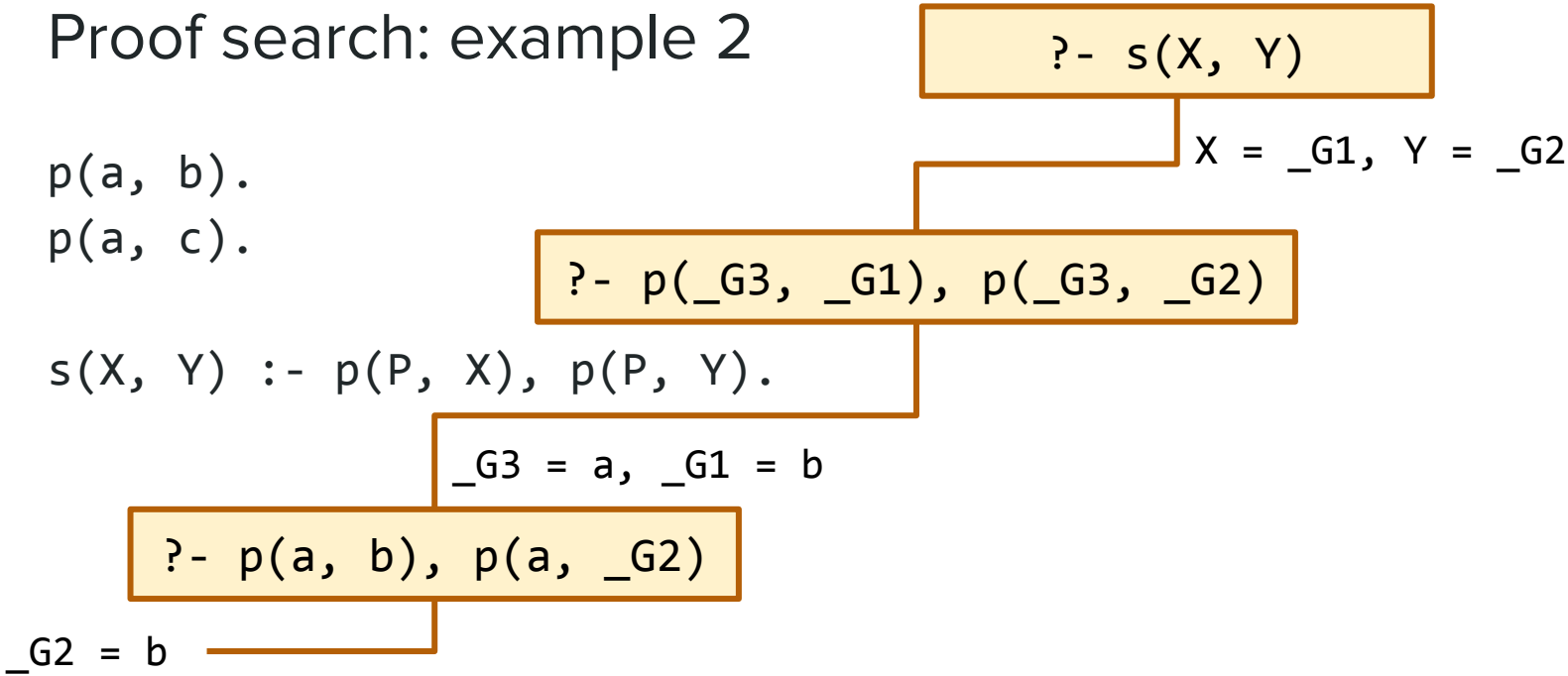

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p(a, b).
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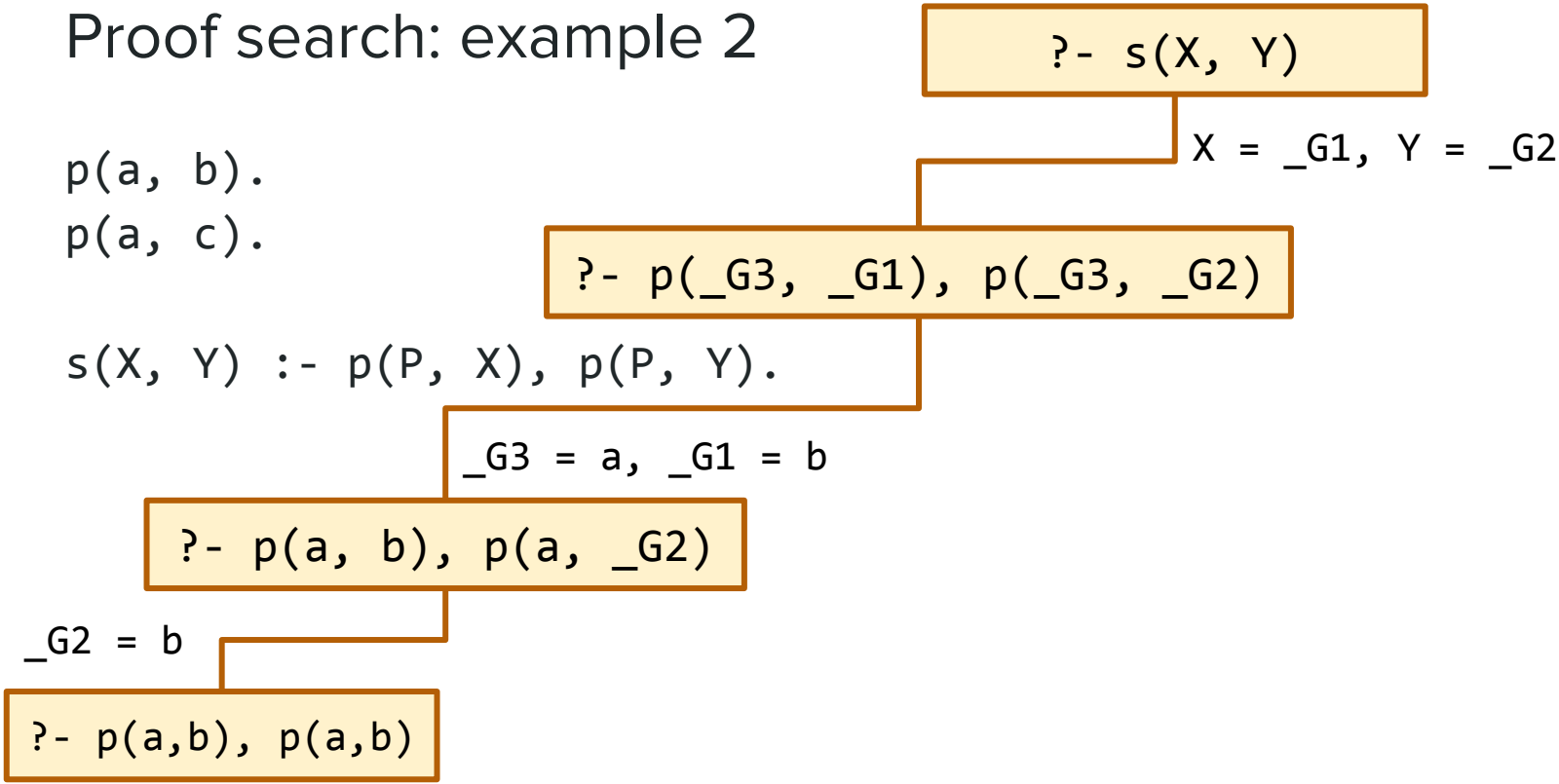

Proof search: example 2

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p(a, b).
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s(X, Y) :- p(P, X), p(P, Y).
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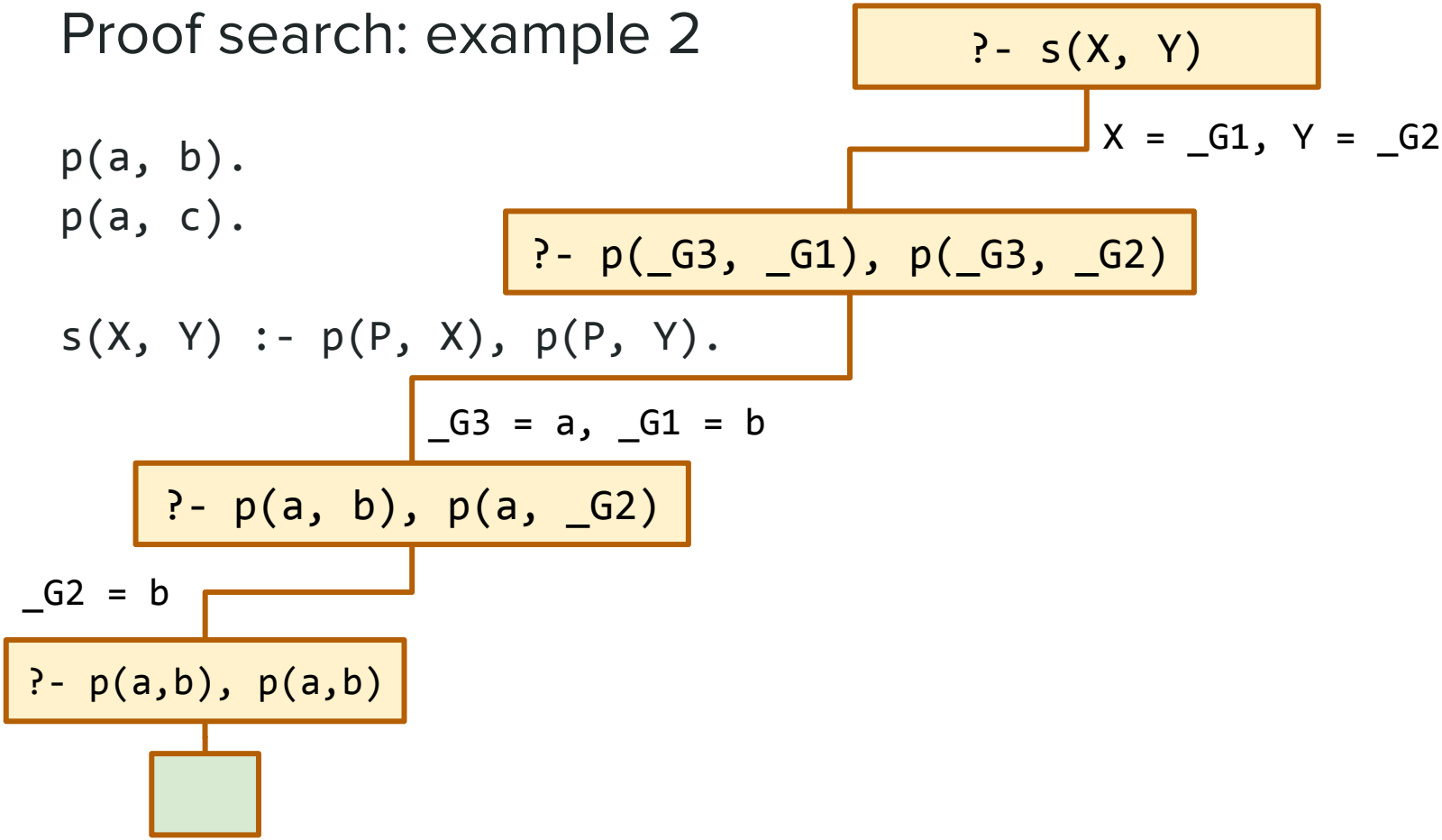

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p(a, b).
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s(X, Y) :- p(P, X), p(P, Y).
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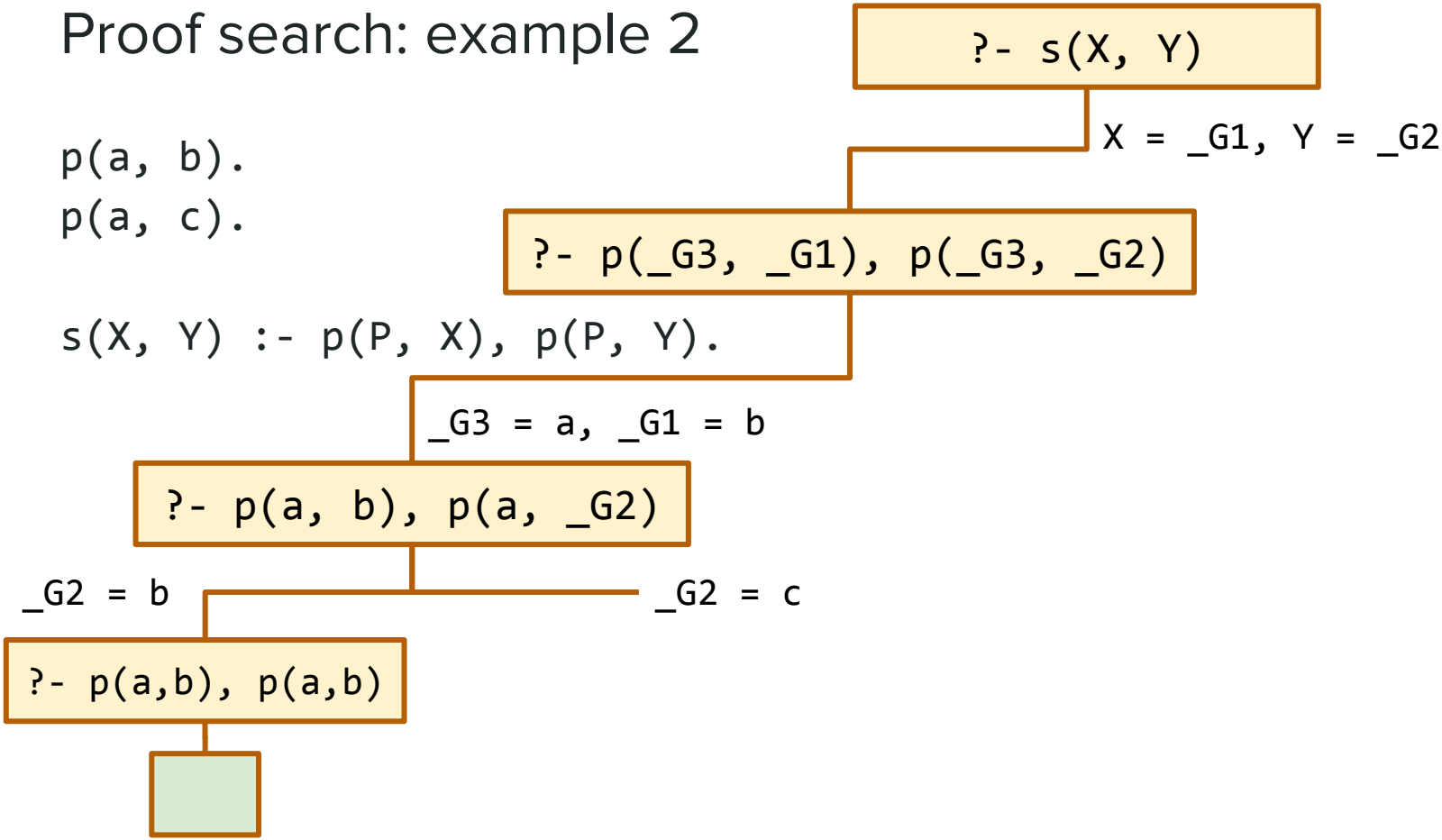

Proof search: example 2

```
p(a, b).
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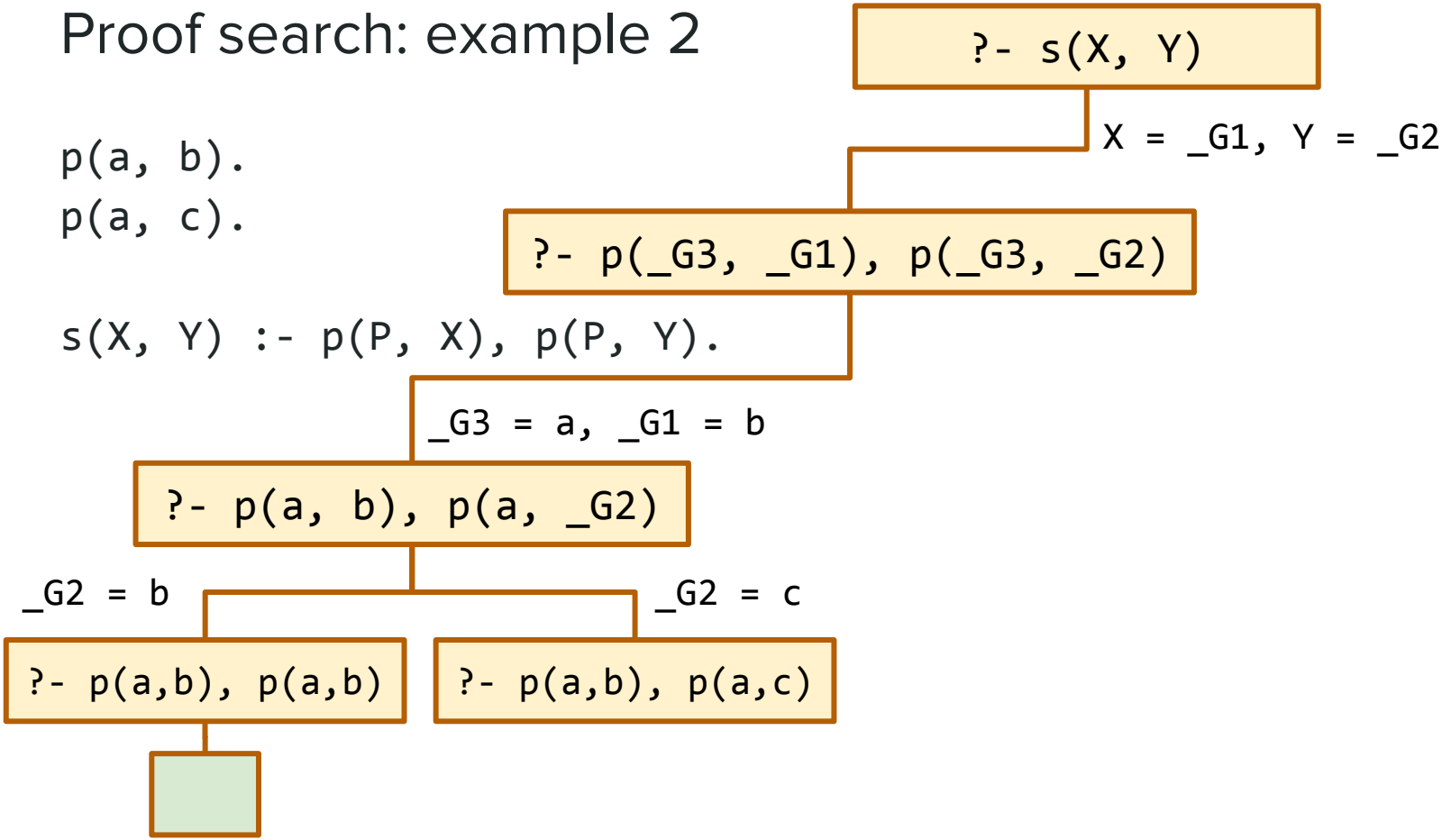
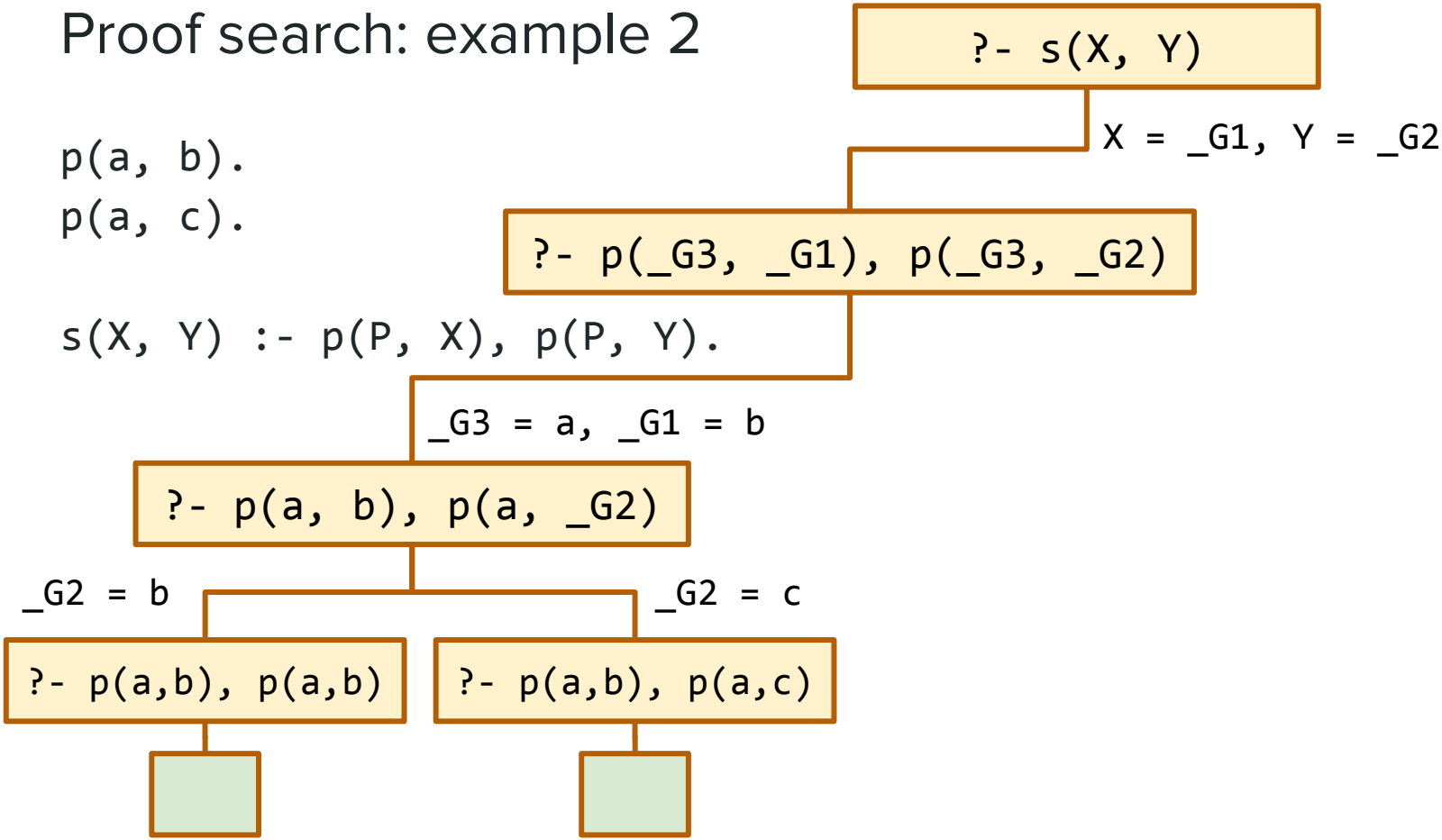
s(X, Y) :- p(P, X), p(P, Y).
```



Proof search: example 2

```
p(a, b).
p(a, c).

s(X, Y) :- p(P, X), p(P, Y).
```



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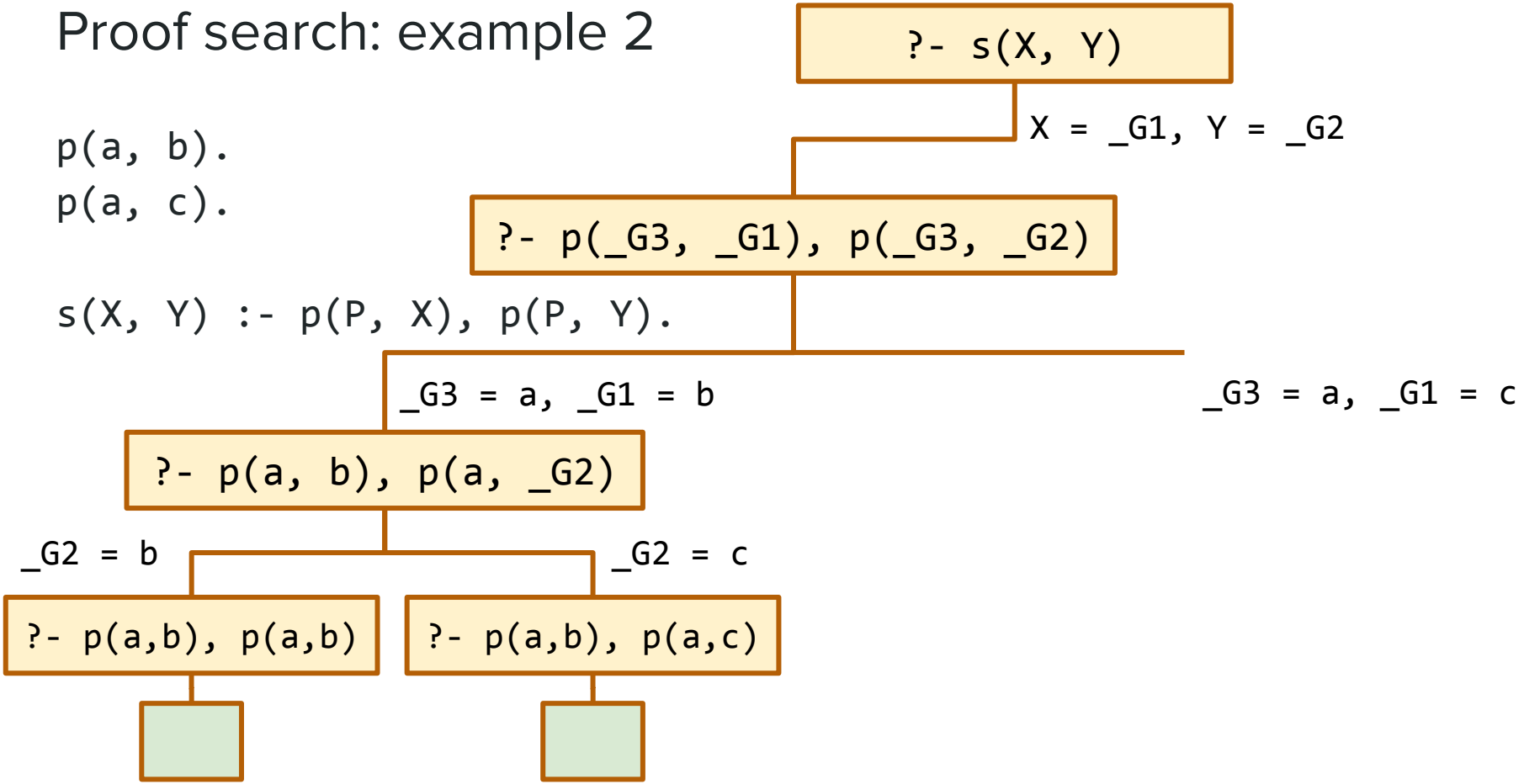

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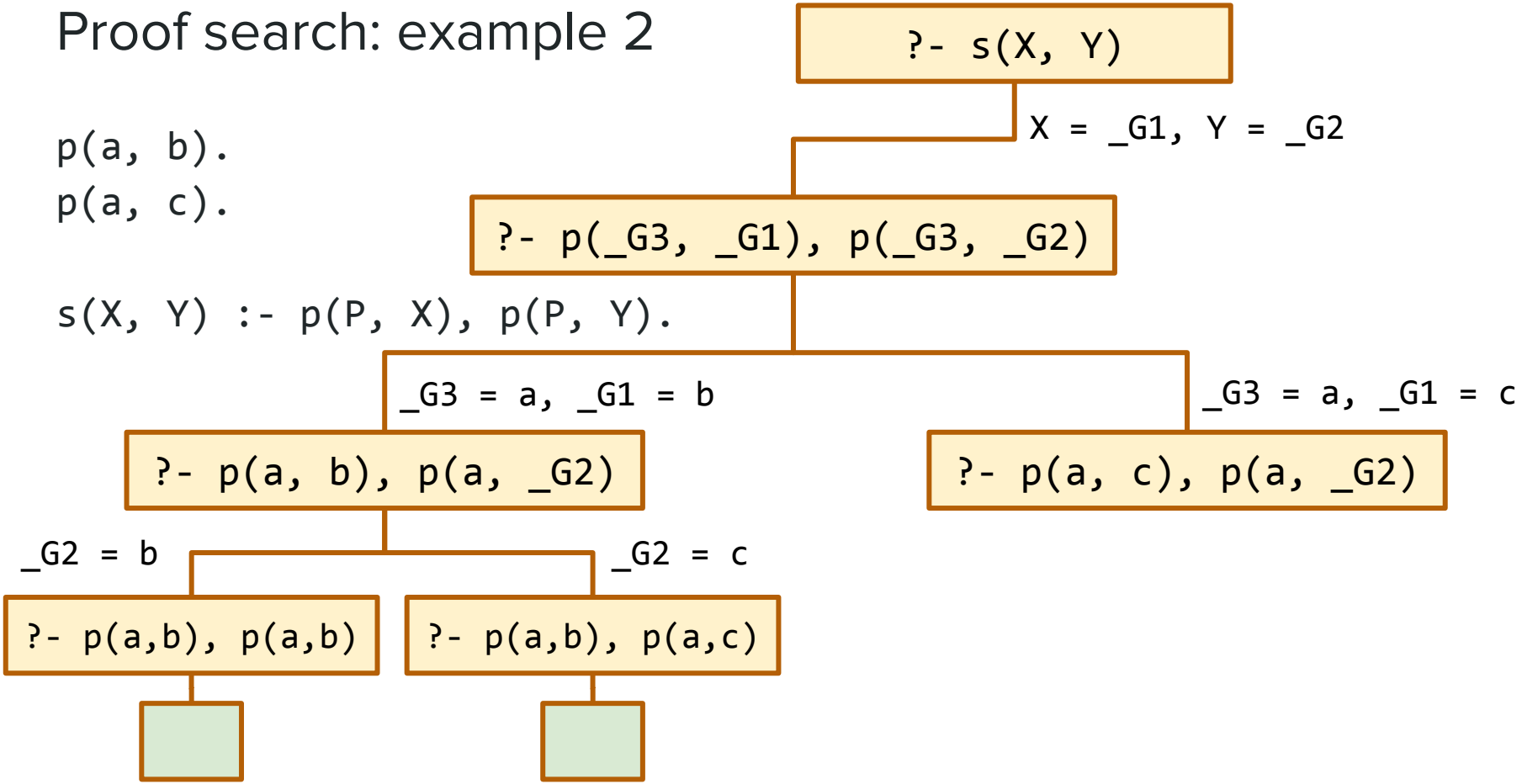

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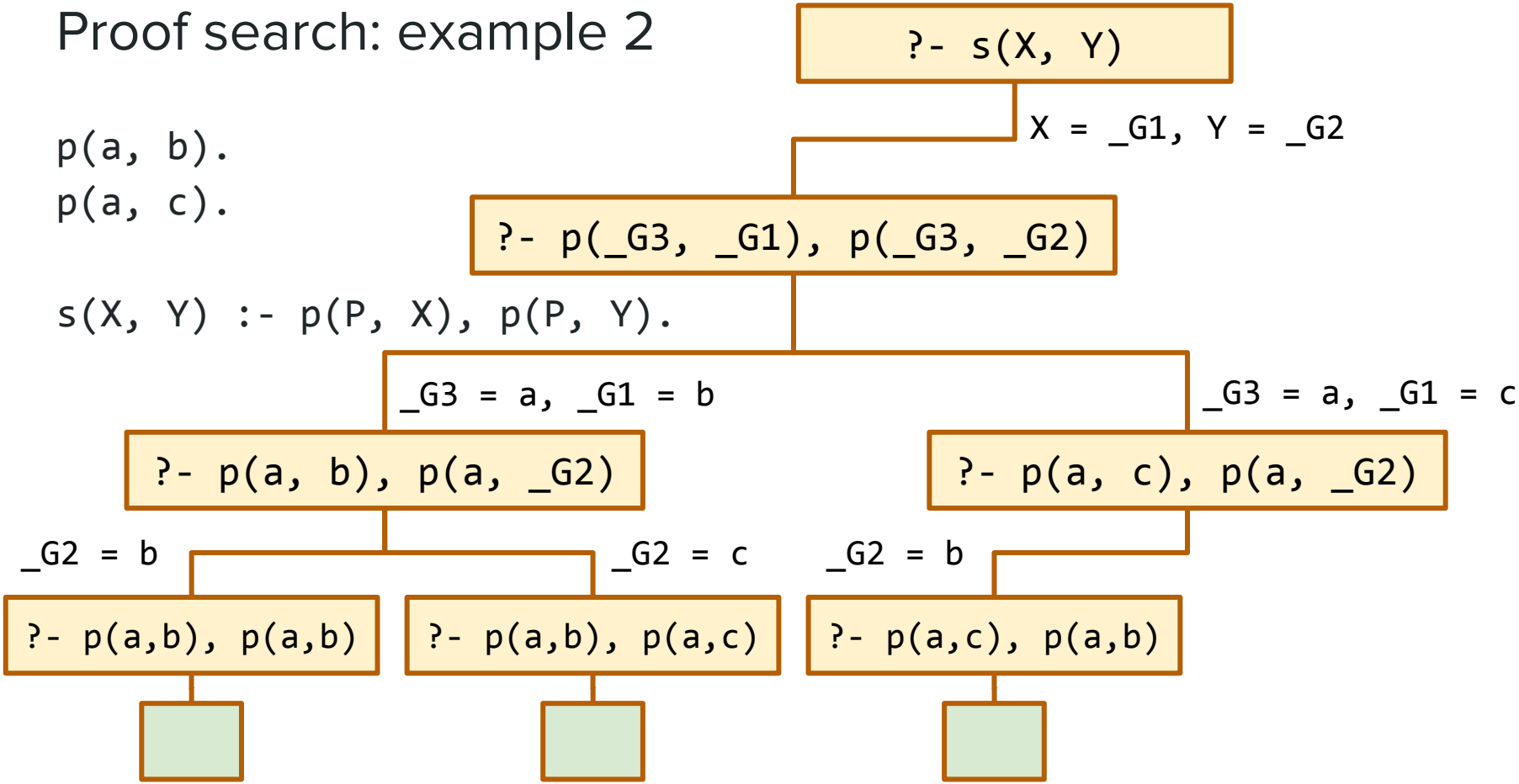

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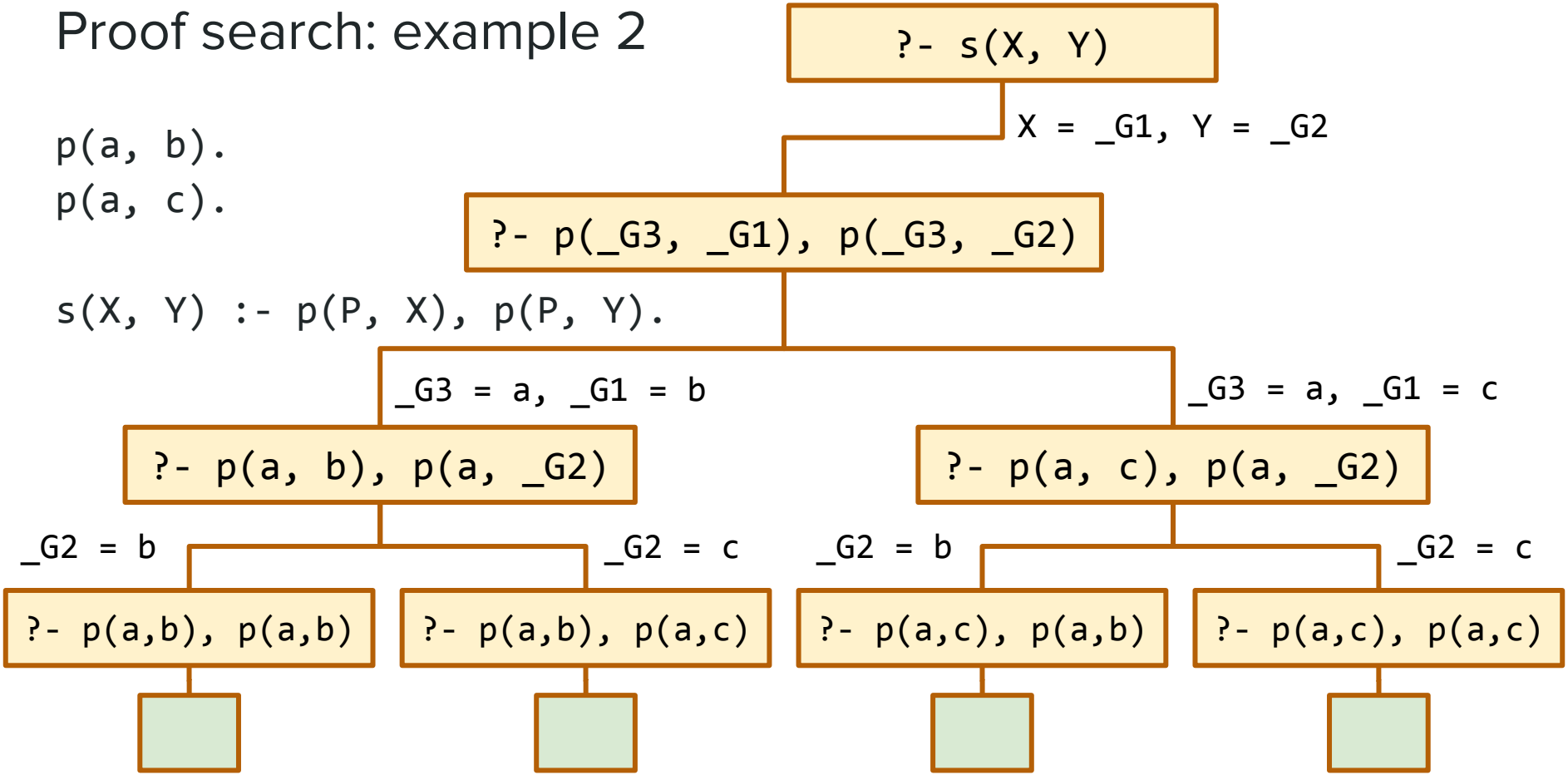

Recursion in Prolog: ancestors

```
parent('Abe', 'Homer').
parent('Homer', 'Bart').
parent('Homer', 'Liza').
parent('Homer', 'Maggy').
```

Recursion in Prolog: ancestors

```
parent('Abe', 'Homer').
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ancestor(X, Y) :- parent(X, Y).
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ancestor(X, Y) :- parent(X, Y).
ancestor(X, Y) :- parent(X, Z), parent(Z, Y).
```

Recursion in Prolog: ancestors

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ancestor(X, Y) :- parent(X, Z), parent(Z, Y).
ancestor(X, Y) :- parent(X, Z), parent(Z, W), parent(W, Y).
...
```

Recursion in Prolog: ancestors

```
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parent('Homer', 'Bart').
parent('Homer', 'Liza').
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ancestor(X, Y) :- parent(X, Y).
ancestor(X, Y) :- parent(X, Z), ancestor(Z, Y).
```

Recursion in Prolog: ancestors

```
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parent('Homer', 'Bart').
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```
?- ancestor(X, Y)
```

Question: Is there a valid answer? Is yes, then how many?

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Recursion in Prolog: unary numbers

```
unary(z).
unary(s(N)) :- unary(N).
```

Recursion in Prolog: unary numbers

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unary(z).
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?- unary(s(s(z))).
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Recursion in Prolog: unary numbers

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unary(s(N)) :- unary(N).


?- unary(s(s(z))).
true
```

Recursion in Prolog: unary numbers

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unary(s(N)) :- unary(N).


?- unary(s(s(z))).
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```

Recursion in Prolog: unary numbers

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unary(z).
unary(s(N)) :- unary(N).


?- unary(s(s(z))).
true

?- unary(s(s(s))).
false
```

Recursion in Prolog: unary numbers

```
unary(z).
unary(s(N)) :- unary(N).
```

```
?- unary(s(s(z))).
true
```

```
?- unary(s(s(s))).
false
```

```
?- unary(N)
```

Question: Is there a valid answer? Is yes, then how many?

Recursion in Prolog: adding unary numbers

```
% add(X, Y, X+Y)
```

Recursion in Prolog: adding unary numbers

```
% add(X, Y, X+Y)
add(z, Y, Y).
```

Recursion in Prolog: adding unary numbers

```
% add(X, Y, X+Y)
add(z, Y, Y).
add(s(X), Y, s(R)) :- add(X, Y, R).
```

Recursion in Prolog: adding unary numbers

```
% add(X, Y, X+Y)
add(z, Y, Y).
add(s(X), Y, s(R)) :- add(X, Y, R).

?- add(s(s(z)), s(z), R).
```

Recursion in Prolog: adding unary numbers

```
% add(X, Y, X+Y)
add(z, Y, Y).
add(s(X), Y, s(R)) :- add(X, Y, R).

?- add(s(s(z)), s(z), R).
R = s(s(s(z))
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Recursion in Prolog: adding unary numbers

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add(s(X), Y, s(R)) :- add(X, Y, R).

?- add(s(s(z)), s(z), R).
R = s(s(s(z))

?- add(s(s(z)), Y, s(s(s(z)))).
```

Recursion in Prolog: adding unary numbers

```
% add(X, Y, X+Y)
add(z, Y, Y).
add(s(X), Y, s(R)) :- add(X, Y, R).

?- add(s(s(z)), s(z), R).
R = s(s(s(z))

?- add(s(s(z)), Y, s(s(s(z)))).
Y = s(z)
```

Recursion in Prolog: adding unary numbers

```
% add(X, Y, X+Y)
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add(s(X), Y, s(R)) :- add(X, Y, R).

?- add(s(s(z)), s(z), R).
R = s(s(s(z))

?- add(s(s(z)), Y, s(s(s(z)))).
Y = s(z)
```

```
?- add(X, Y, s(s(s(z))))
```

Question: Is there a valid answer? Is yes, then how many?

Homework (self-study)

1. Read **Chapters 4 and 5** of Learn Prolog Now!
   http://www.let.rug.nl/bos/lpn/lpnpage.php?pagetype=html&pageid=lpn-htmlch1
2. Work through the **exercises** from both chapters, using SWISH
   https://swish.swi-prolog.org

What was the most unclear part of the lecture for you?

See Moodle

References

1. Learn Prolog Now!