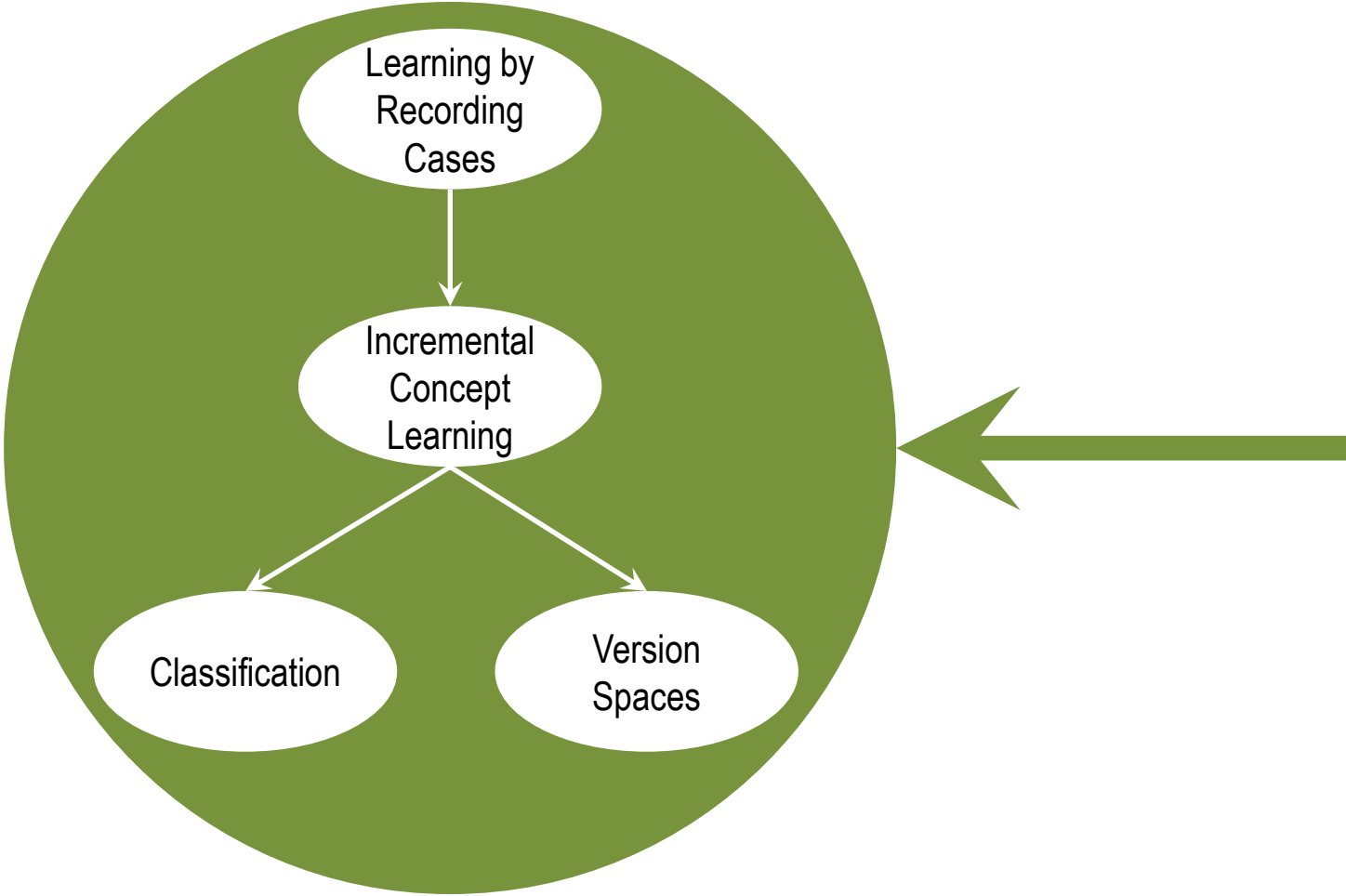
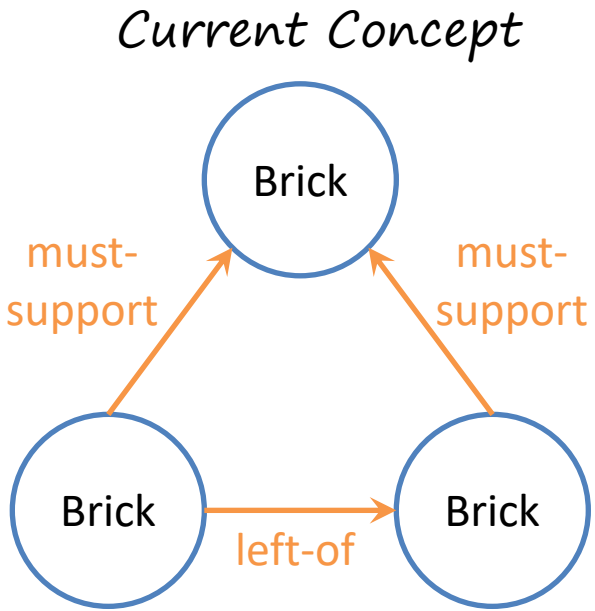

Version
Spaces

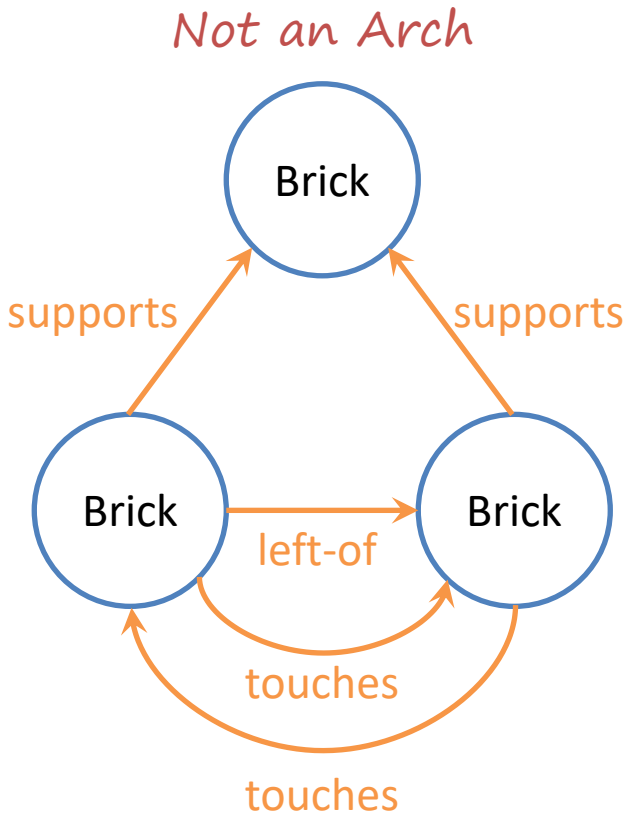
Learning

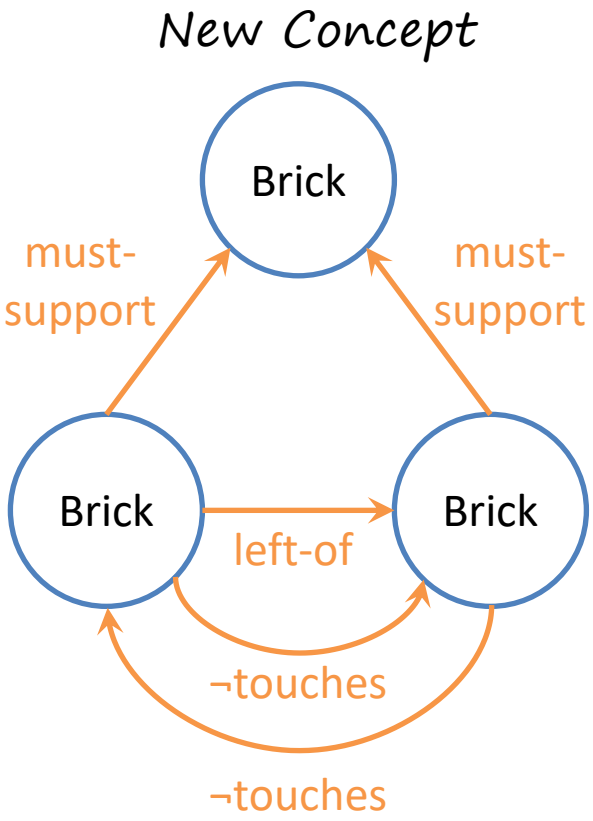

Learning by Recording Cases
Incremental Concept Learning
Classification
Version Spaces

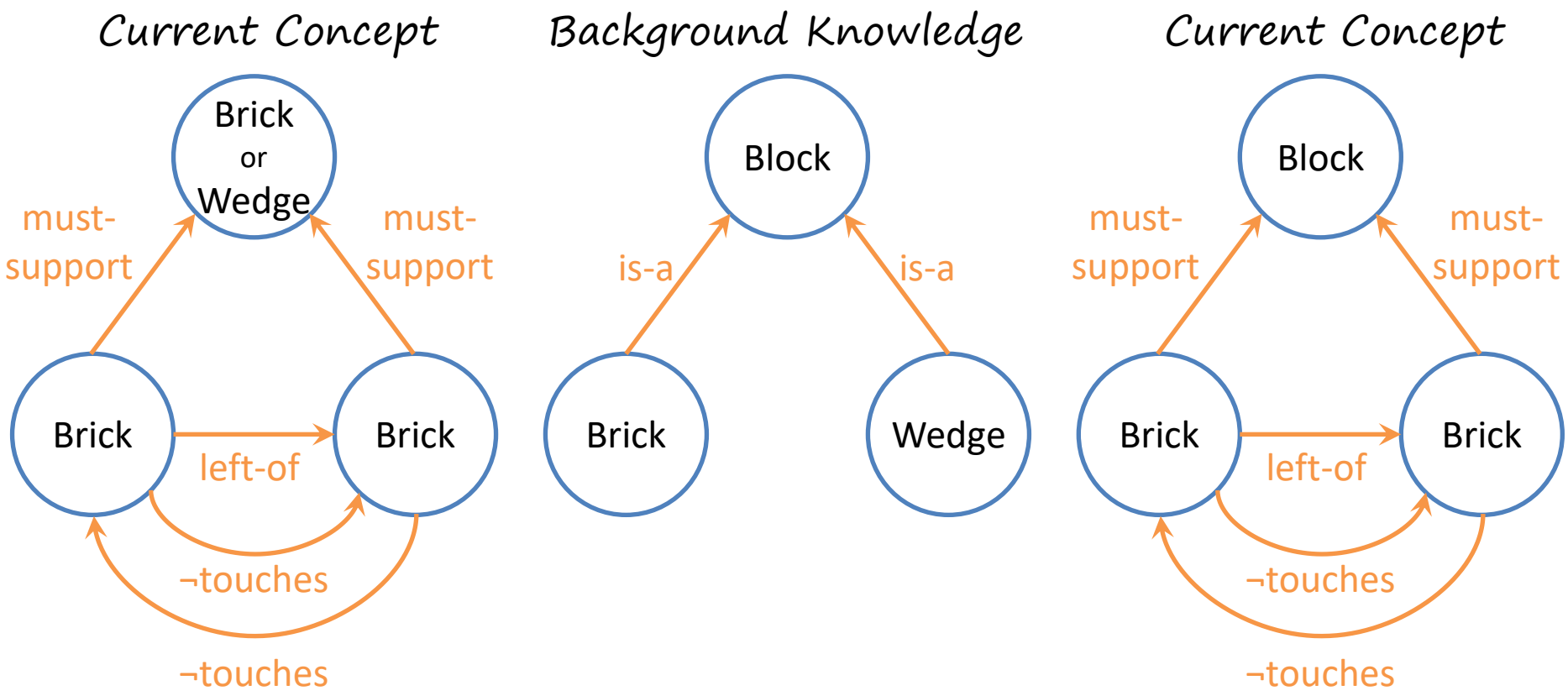
Lesson Preview

- Definition
- Abstract version spaces
- Algorithm for version spaces
- Identification trees

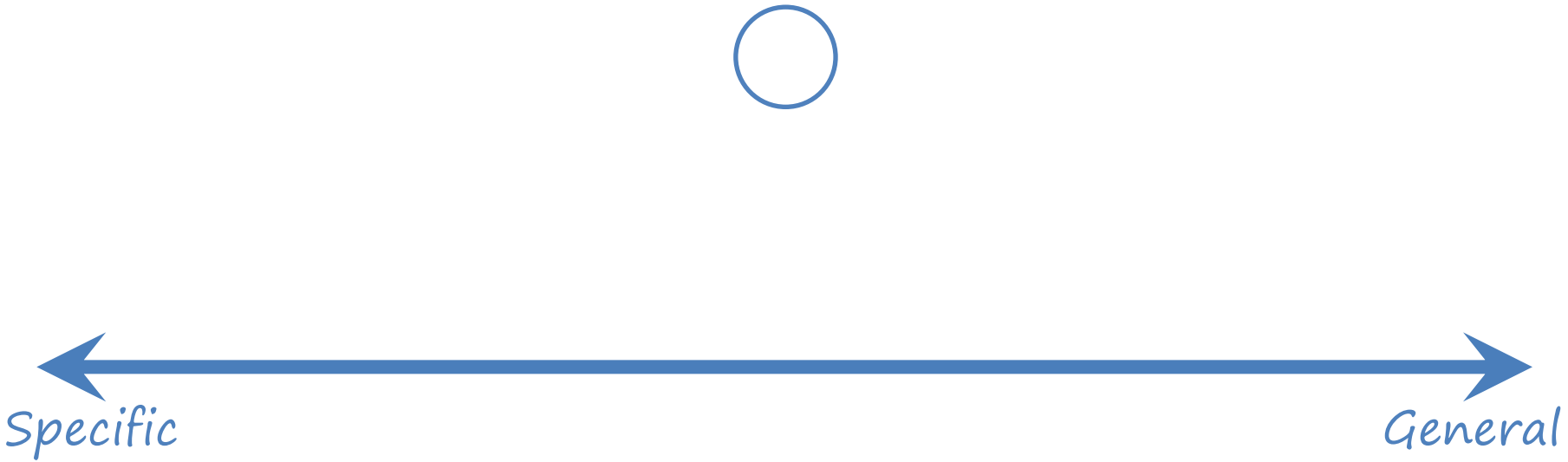

Current Concept
Brick
must-support
must-support
Brick
left-of
Brick


Not an Arch
Brick
supports
supports
Brick
left-of
Brick
touches
touches


New Concept
Brick
must-support
must-support
Brick
left-of
Brick
¬touches
¬touches


Current Concept
Brick
or
Wedge
must-
support
must-
support
Brick
Brick
left-of
¬touches
¬touches
Background Knowledge
Block
is-a
is-a
Brick
Wedge
Current Concept
Block
must-
support
must-
support
Brick
Brick
left-of
¬touches
¬touches

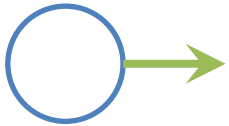
Incremental Concept Learning



Incremental Concept Learning

Example #1:

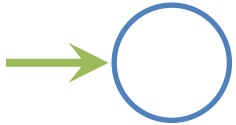
Positive



Incremental Concept Learning

Example #1:

Positive



Incremental Concept Learning

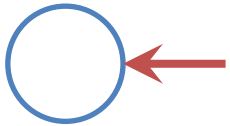
Example #2:

Negative

Incremental Concept Learning

Example #2:

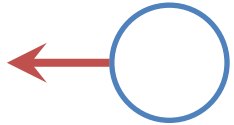
Negative



Incremental Concept Learning

Example #3:

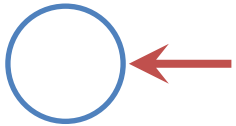
Negative



Incremental Concept Learning

Example #3:

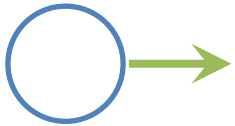
Negative



Incremental Concept Learning

Example #4:

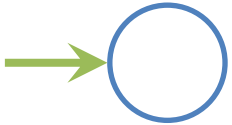
Positive



Incremental Concept Learning

Example #4:

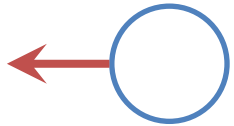
Positive



Incremental Concept Learning

Example #5:

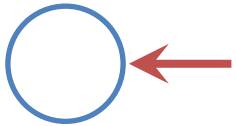
Negative



Incremental Concept Learning

Example #5:

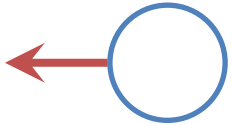
Negative



Incremental Concept Learning

Example #6:

Negative



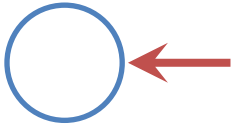
Specific

General

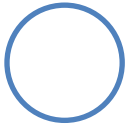
Incremental Concept Learning

Example #6:

Negative



Incremental Concept Learning



Version Spaces

Version Spaces

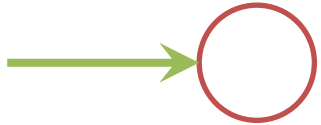
Example #1:
Positive

Specific

General

Version Spaces

Example #1:
Positive

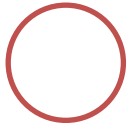


Specific

General

Version Spaces

Example #2:
Negative



Specific

General

Version Spaces

Example #2:
Negative

Version Spaces

Example #3:
Negative

Version Spaces

Example #3:
Negative

Version Spaces

Example #4:
Positive

Version Spaces

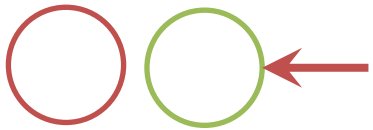
Example #4:
Positive

Version Spaces

Example #5:
Negative

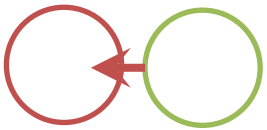
Version Spaces

Example #5:
Negative



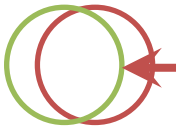
Version Spaces

Example #6:
Negative



Version Spaces

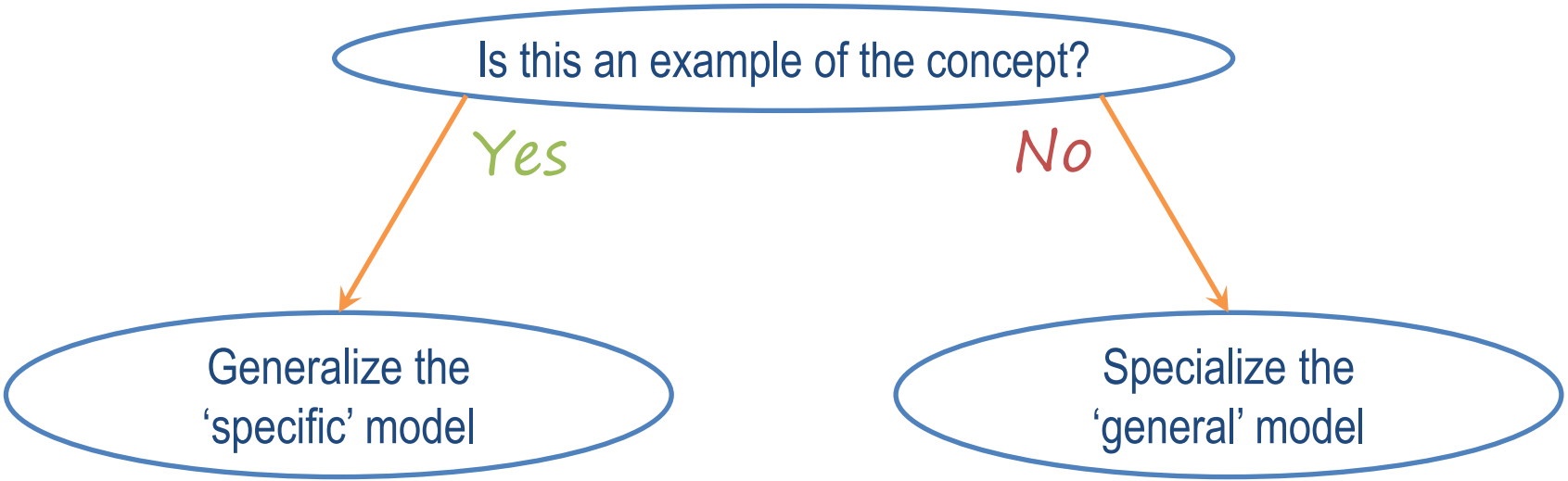
Example #6:
Negative

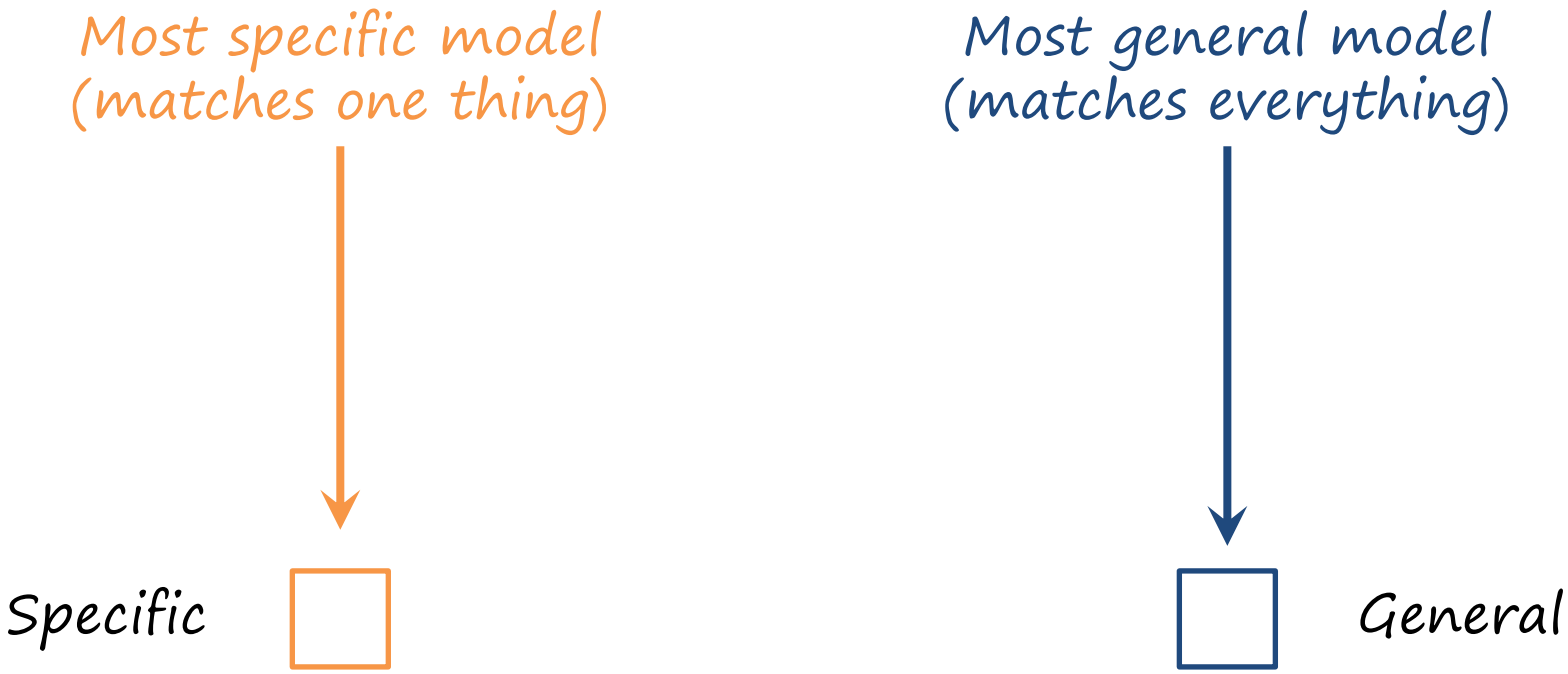


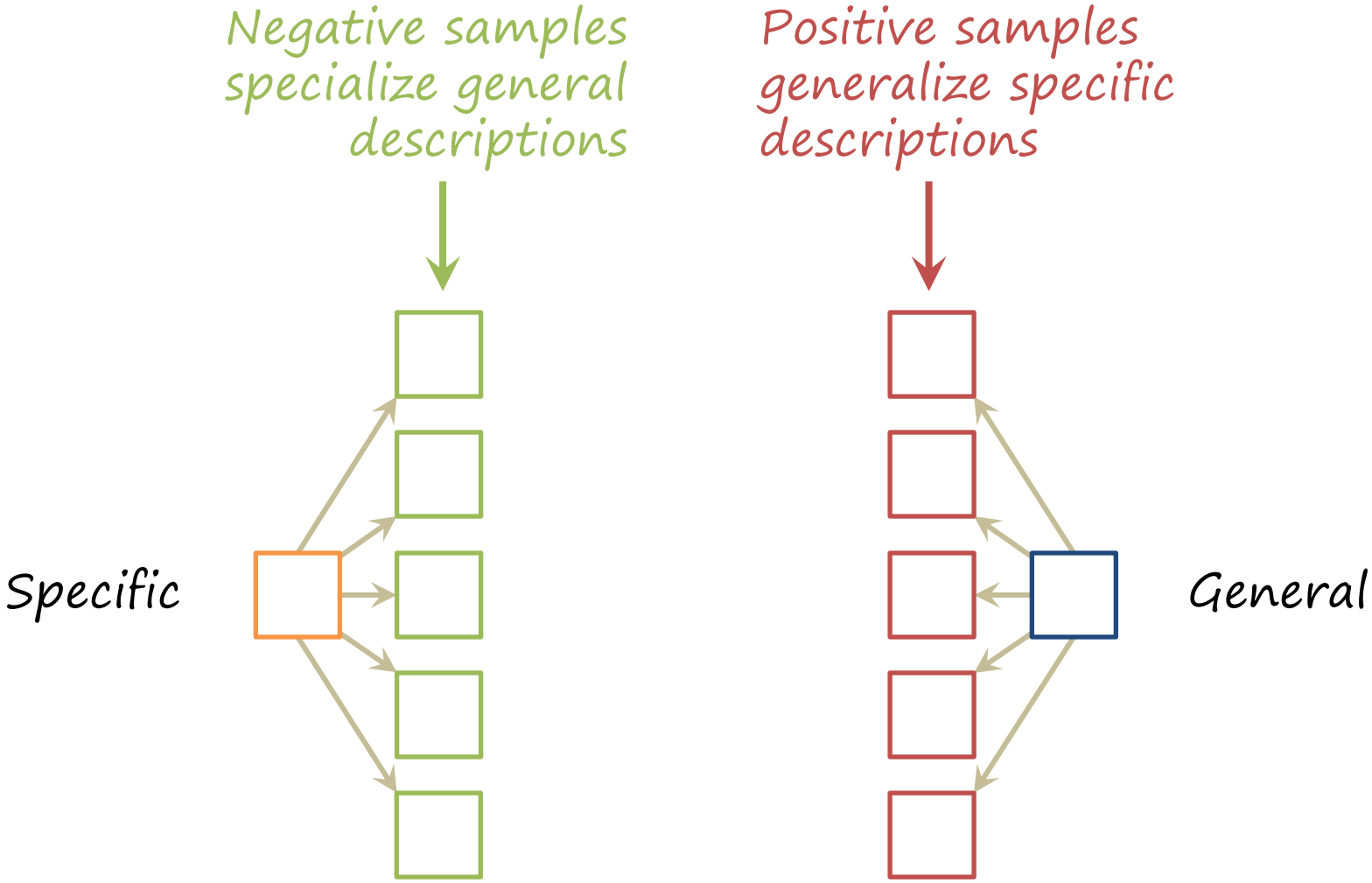
Version Spaces

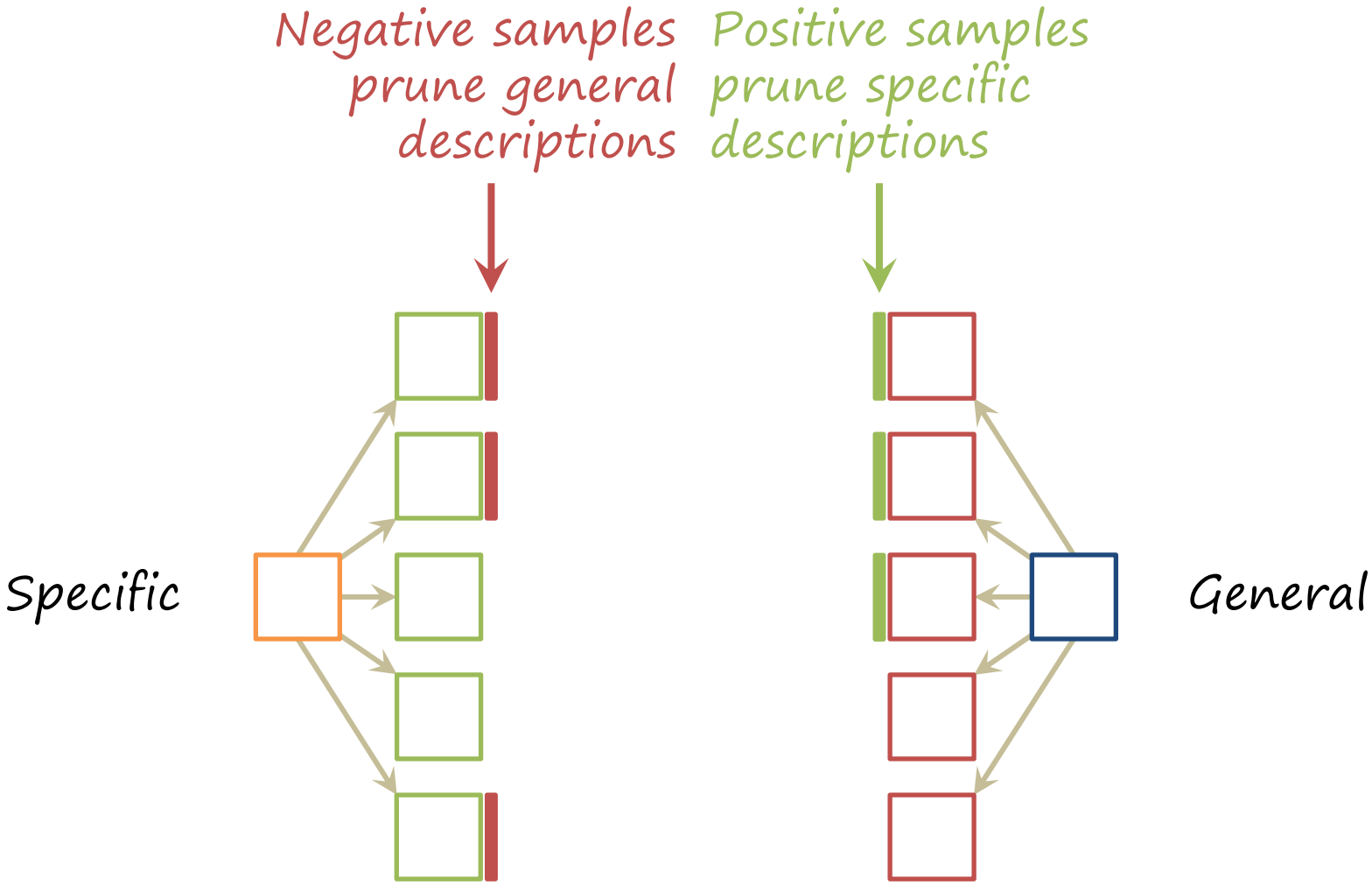
Incremental Concept Learning

Given new example:

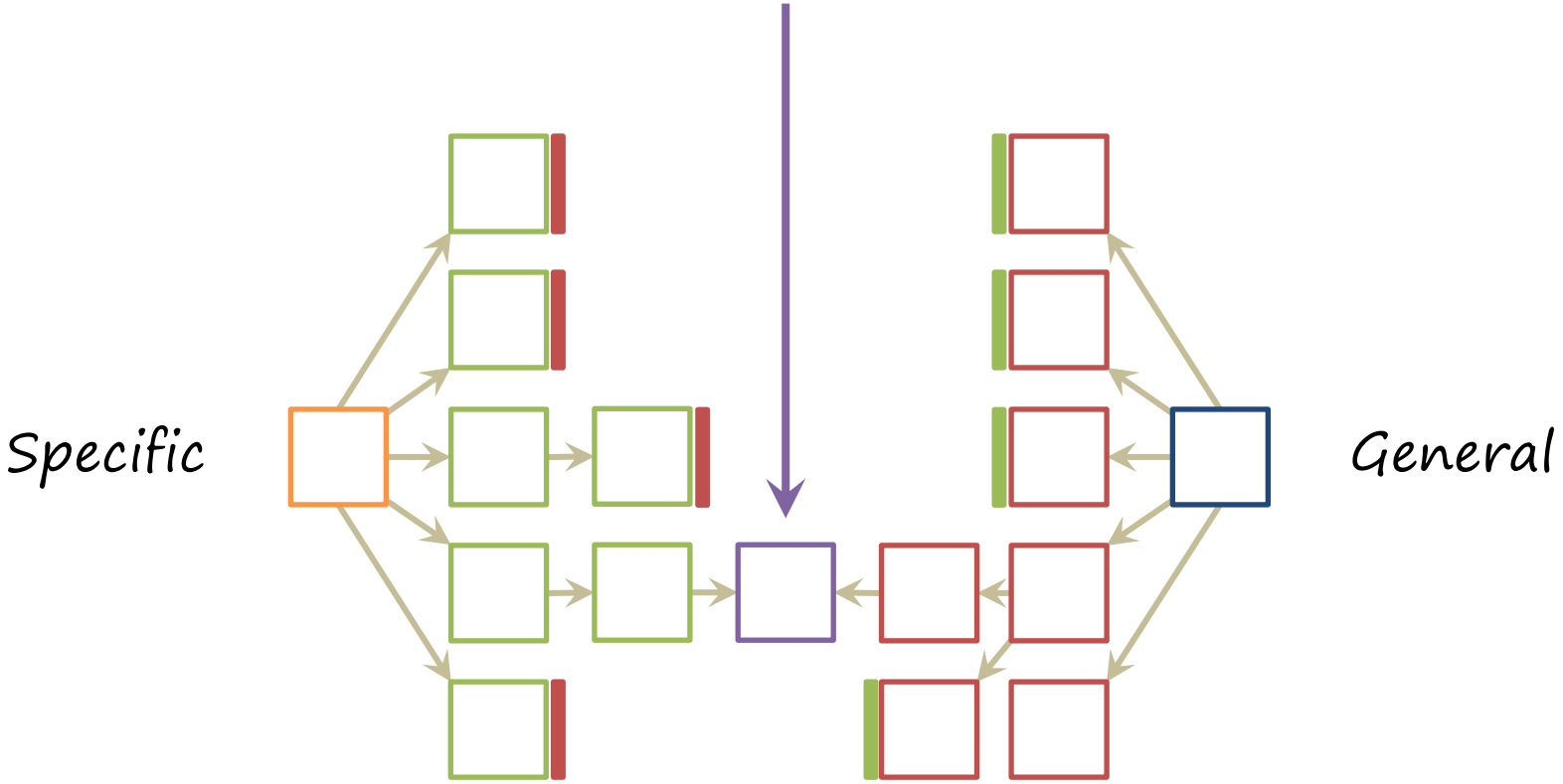



Most specific model
(matches one thing)
Specific
Most general model
(matches everything)
General


Negative samples specialize general descriptions
Positive samples generalize specific descriptions
Specific
General


Negative samples
prune general
descriptions
Positive samples
prune specific
descriptions
Specific
General

Positive and negative samples force models to converge



Number	Restaurant	Meal	Day	Cost	Allergic Reaction?
Visit1	Sam's	Breakfast	Friday	Cheap	Yes
Visit2	Kim's	Lunch	Friday	Expensive	No
Visit3	Sam's	Lunch	Saturday	Cheap	Yes
Visit4	Bob's	Breakfast	Sunday	Cheap	No
Visit5	Sam's	Breakfast	Sunday	Expensive	No

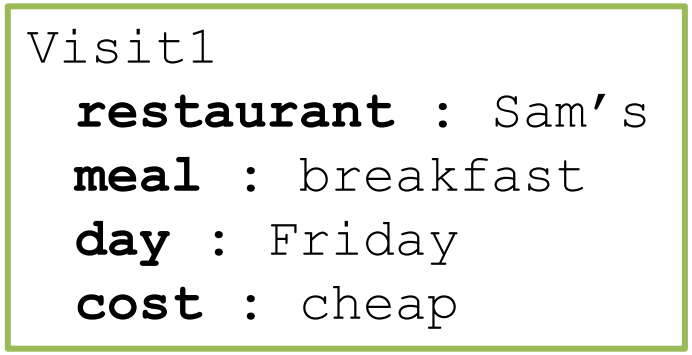
Visit1

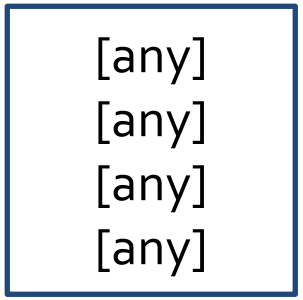
restaurant : Sam’s

meal : breakfast

day : Friday

cost : cheap





Specific

General

Visit2
restaurant : Kim's
meal : lunch
day : Friday
cost : expensive

Sam's
breakfast
Friday
cheap

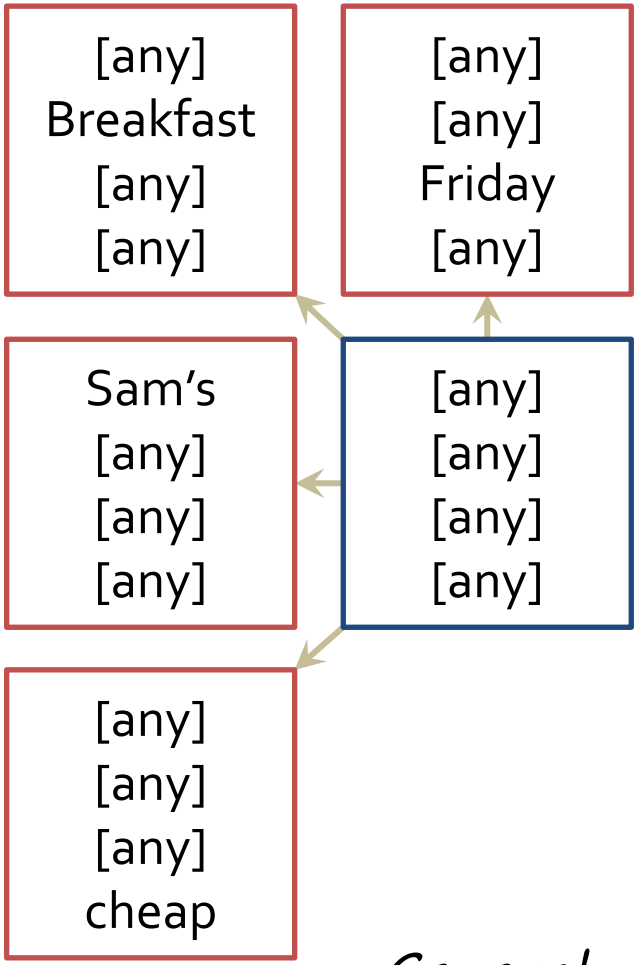
[any]
[any]
[any]
[any]

Specific

General

Visit2
restaurant : Kim's
meal : lunch
day : Friday
cost : expensive

Sam's
breakfast
Friday
cheap

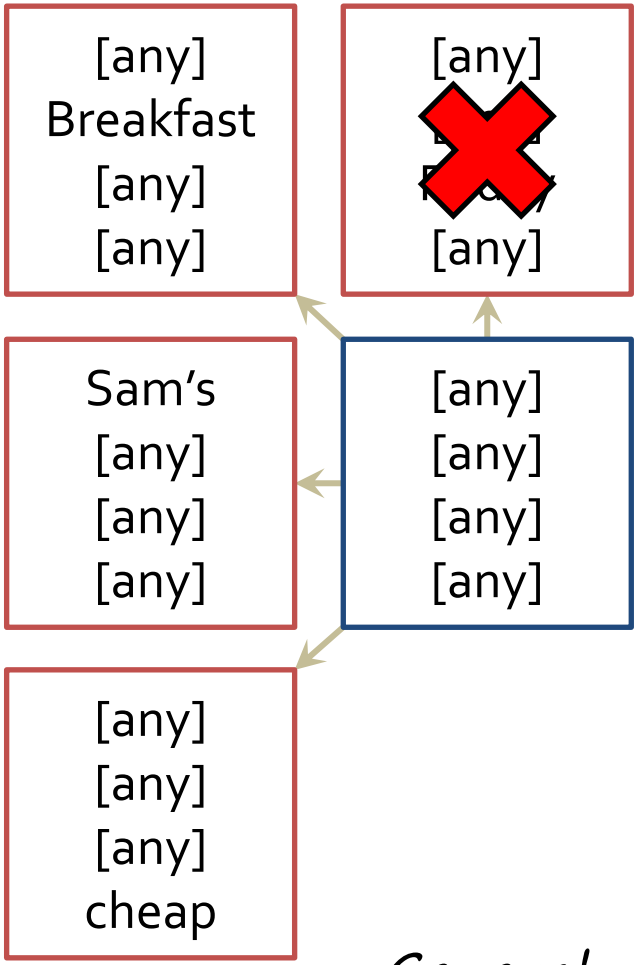


Specific

General

Visit2
restaurant : Kim's
meal : lunch
day : Friday
cost : expensive

Sam's
breakfast
Friday
cheap

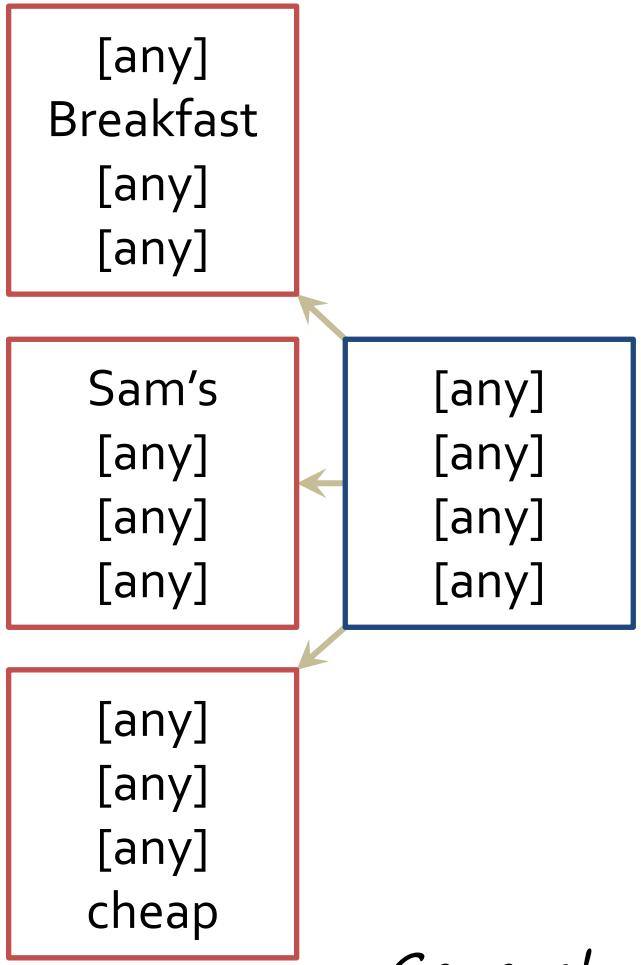


Specific

General

Visit2
restaurant : Kim's
meal : lunch
day : Friday
cost : expensive

Sam's
breakfast
Friday
cheap

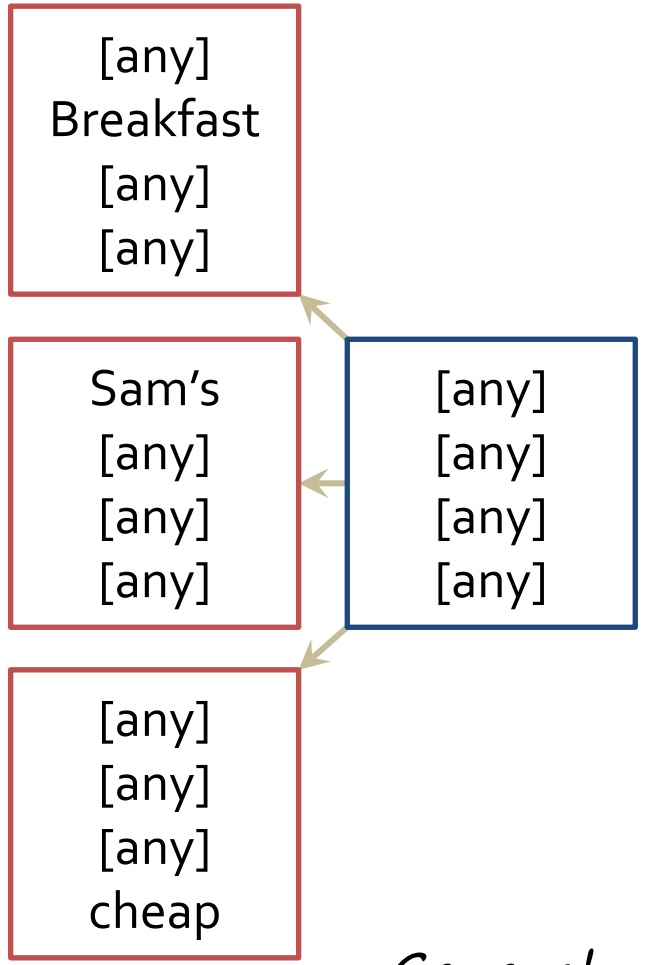


Specific

General

Visit3
restaurant : Sam's
meal : lunch
day : Saturday
cost : cheap

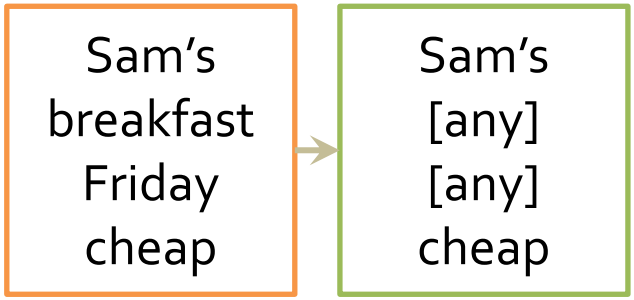
Sam's
breakfast
Friday
cheap

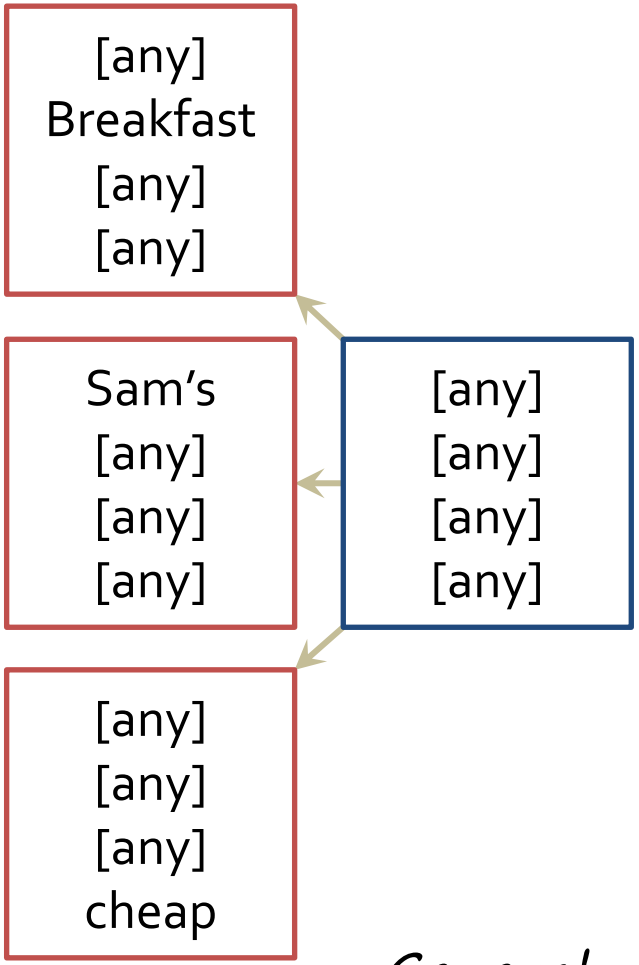


Specific

General

Visit3
restaurant : Sam's
meal : lunch
day : Saturday
cost : cheap





Specific

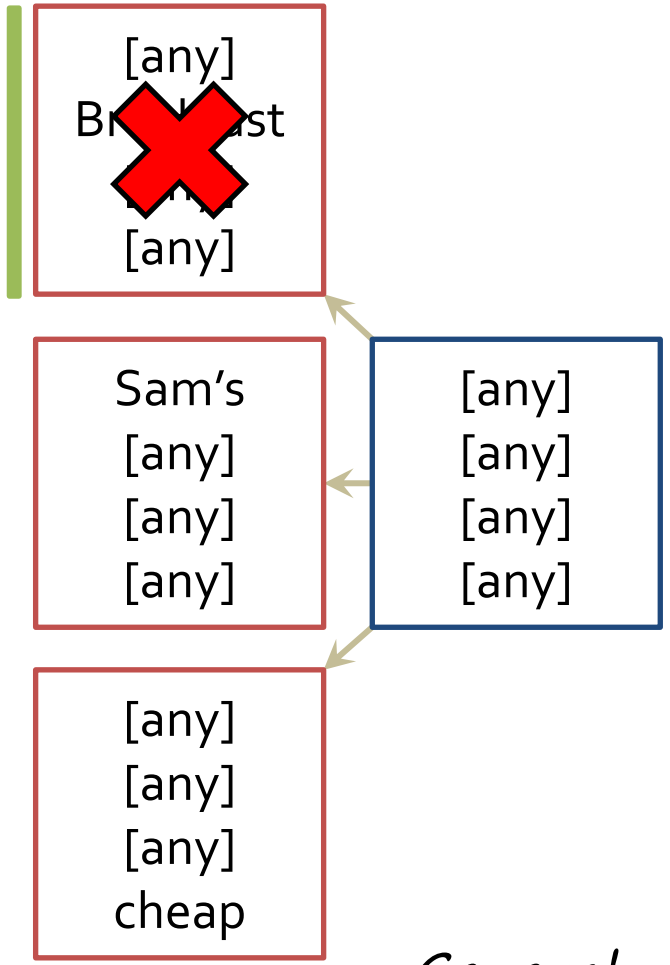
General

Visit3
restaurant : Sam's
meal : lunch
day : Saturday
cost : cheap

Sam's
breakfast
Friday
cheap

→

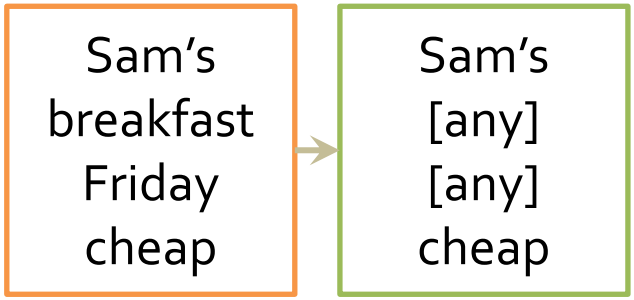
Sam's
[any]
[any]
cheap

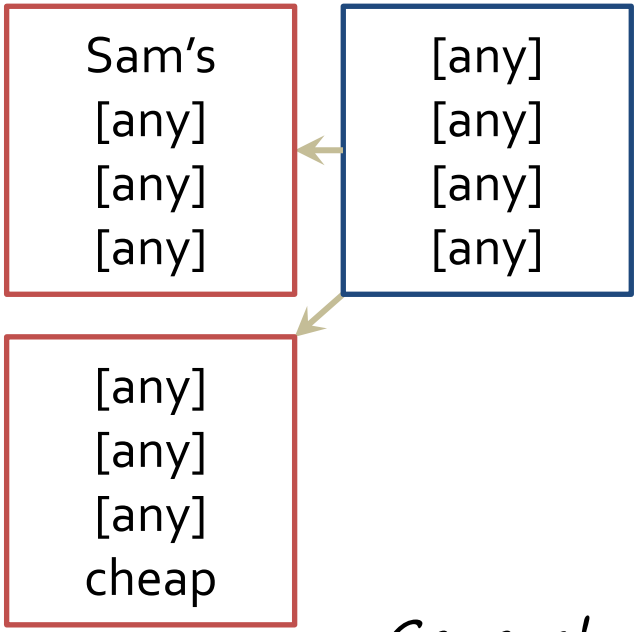


Specific

General

```
Visit3
  restaurant : Sam's
  meal : lunch
  day : Saturday
  cost : cheap
```

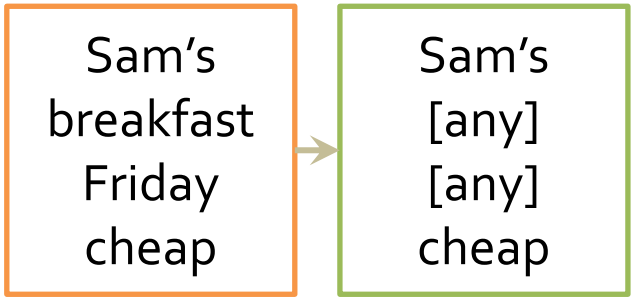


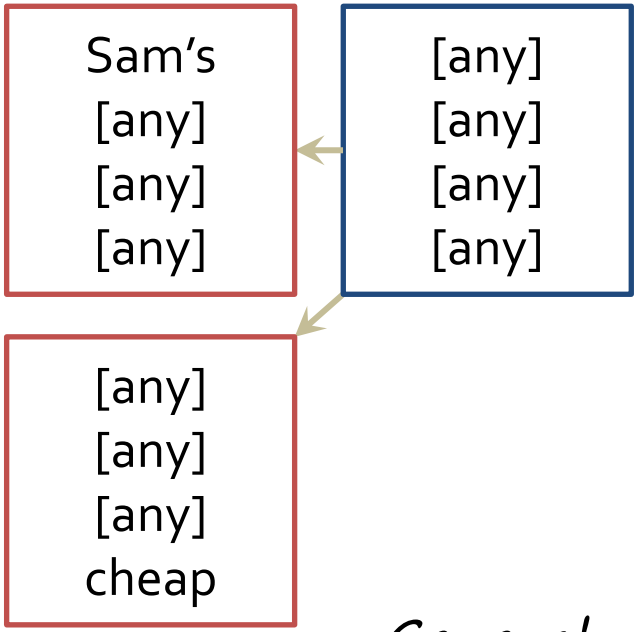


Specific

General

Visit4
restaurant : Bob's
meal : Breakfast
day : Sunday
cost : cheap

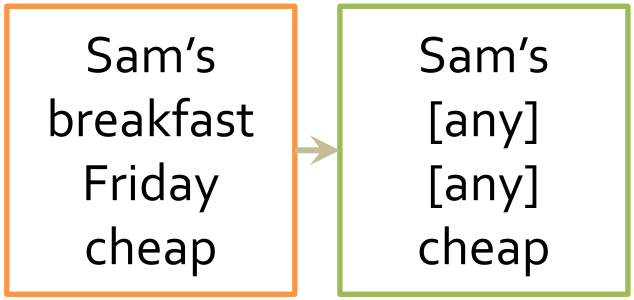


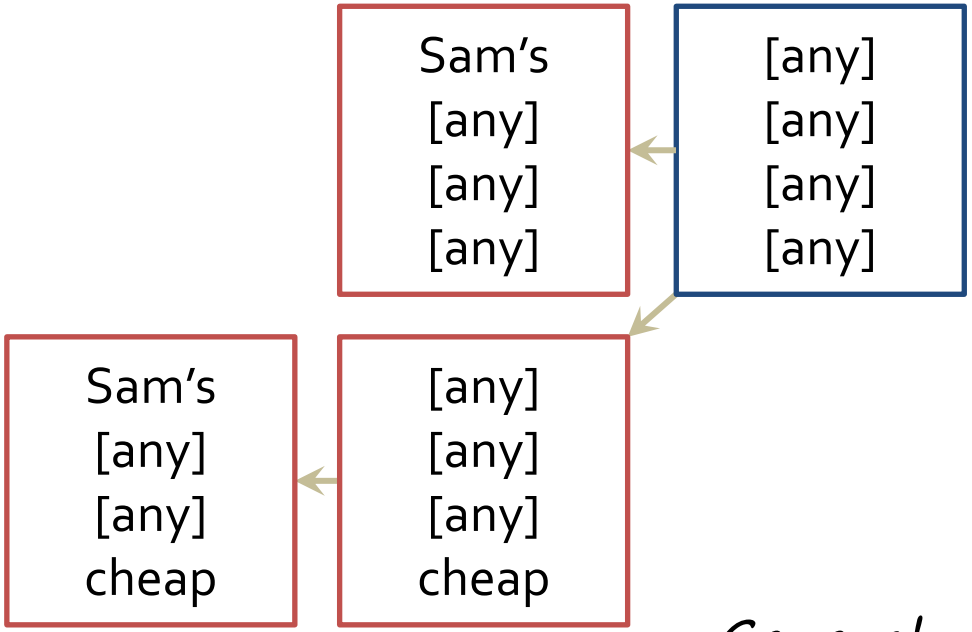


Specific

General

Visit4
restaurant : Bob's
meal : Breakfast
day : Sunday
cost : cheap

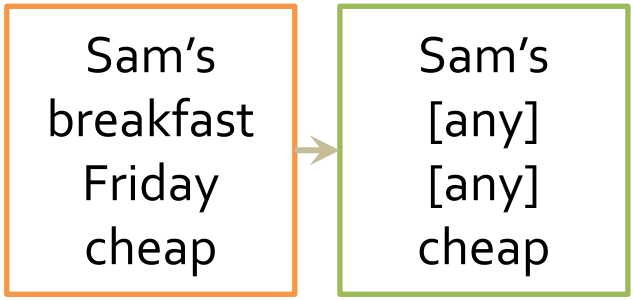


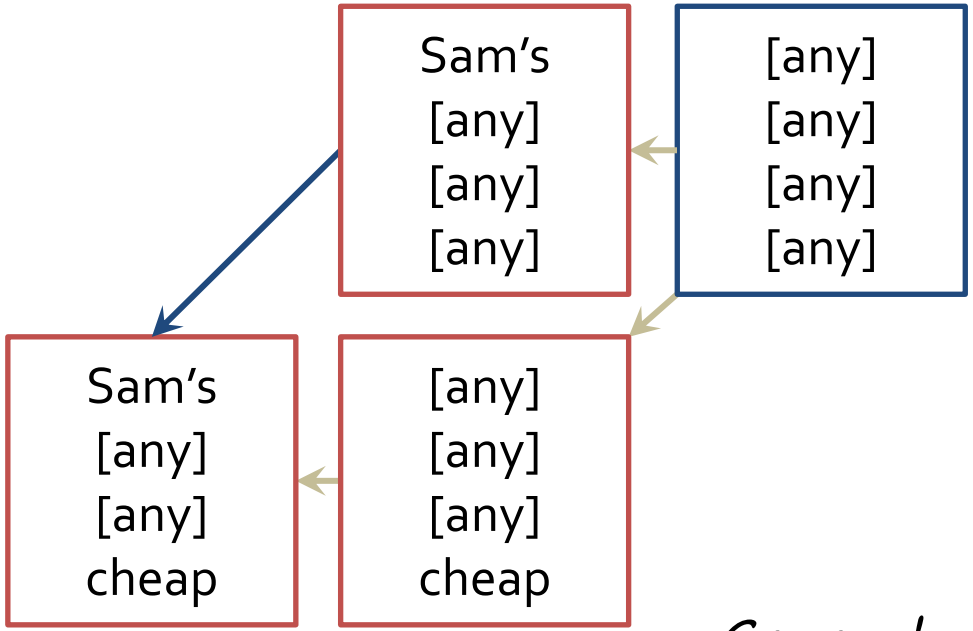


Specific

General

Visit4
restaurant : Bob's
meal : Breakfast
day : Sunday
cost : cheap

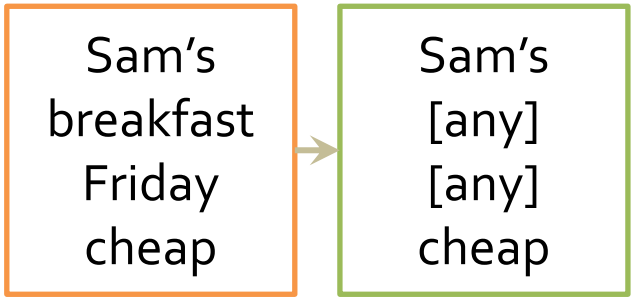


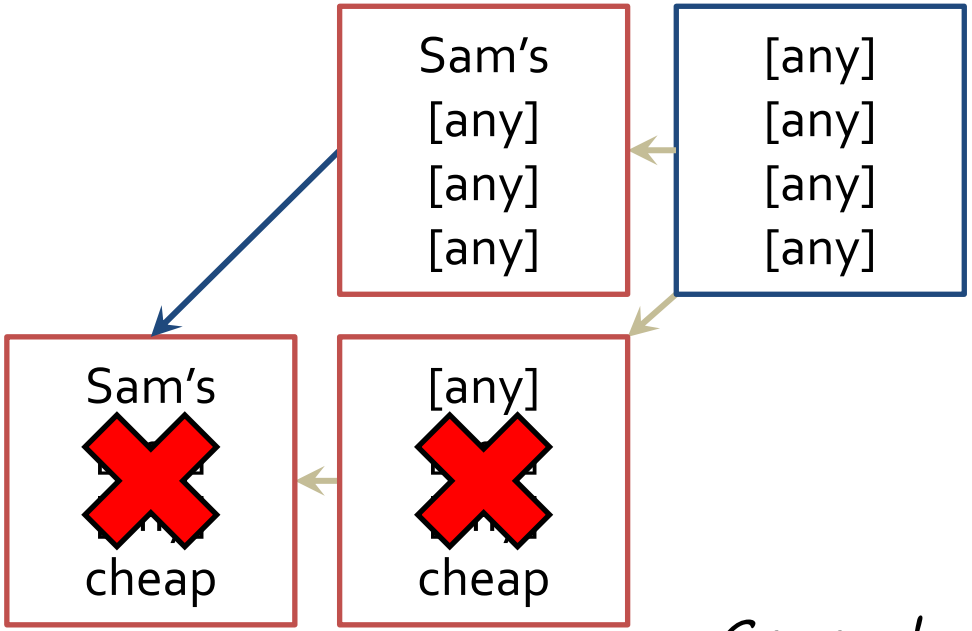


Specific

General

```
Visit4
  restaurant : Bob's
  meal : Breakfast
  day : Sunday
  cost : cheap
```

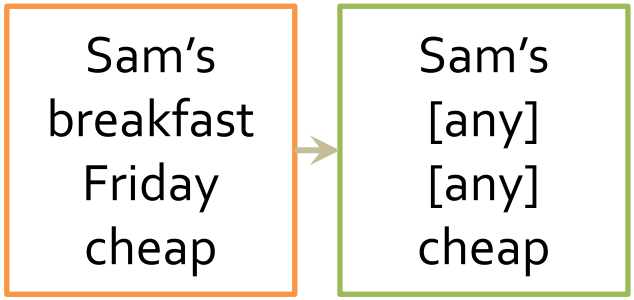


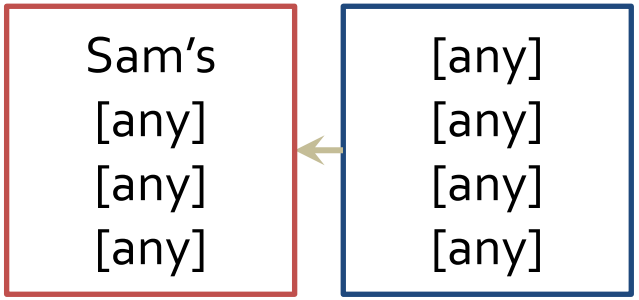


Specific

General

Visit4
restaurant : Bob's
meal : Breakfast
day : Sunday
cost : cheap

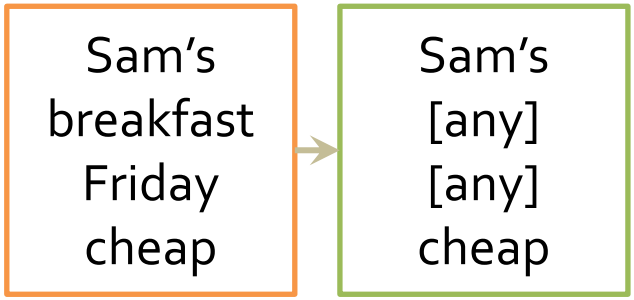


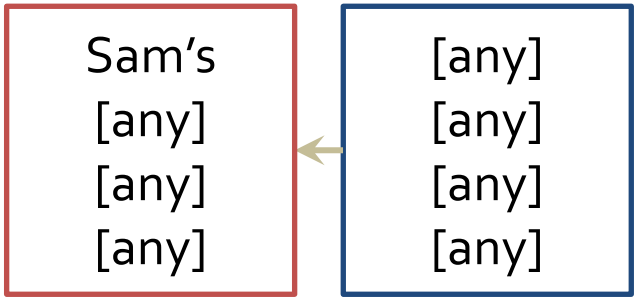


Specific

General

Visit5
restaurant : Sam's
meal : Breakfast
day : Sunday
cost : expensive

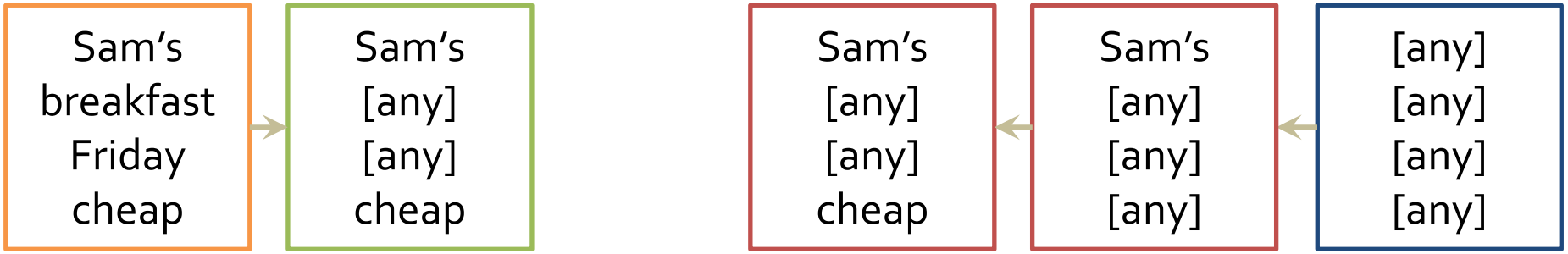




Specific

General

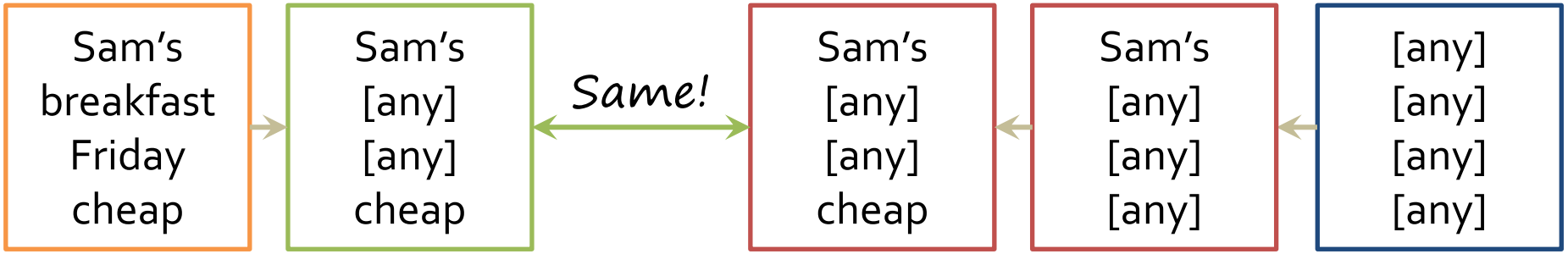
Visit5
restaurant : Sam's
meal : Breakfast
day : Sunday
cost : expensive



Specific

General

Visit5
restaurant : Sam's
meal : Breakfast
day : Sunday
cost : expensive



Specific

General

Algorithm for Version Spaces

For each example:

If the example is **positive**:
- **Generalize** all **specific** models to include it
- Prune away **general** models that cannot include it

If the example is **negative**:
- **Specialize** all **general** models to include it
- Prune away **specific** models that cannot include it

Prune away any models **subsumed** by other models

Number	Meal	Meal	Day	Cost	Vegan	Reaction?
Visit1	Kim's	Breakfast	Friday	Cheap	No	Yes
Visit2	Kim's	Lunch	Friday	Cheap	No	Yes
Visit3	Sam's	Lunch	Saturday	Cheap	No	No
Visit4	Kim's	Breakfast	Sunday	Cheap	Yes	No
Visit5	Sam's	Breakfast	Sunday	Expensive	Yes	No
Visit6	Kim's	Lunch	Saturday	Cheap	No	Yes
Visit7	Kim's	Lunch	Monday	Expensive	No	No

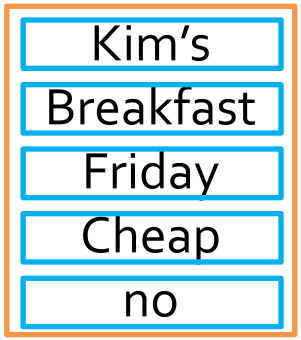
What model did you converge on?

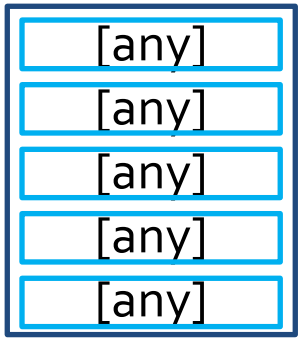
Kim's [any] [any] Cheap [any]	[any] [any] [any] [any] [any]	[any] Lunch Friday [any] No	Kim's Lunch Friday Cheap No	Kim's [any] [any] Cheap No	[any] [any] [any] Cheap No

Visit1

restaurant : Kim's **meal** : Breakfast **day** : Friday

cost : Cheap **vegan** : no





What would the initial general and specific models be?

Visit2

restaurant : Kim's **meal** : Lunch **day** : Friday

cost : Cheap **vegan** : no

Kim's
Breakfast
Friday
Cheap
no

[any]
[any]
[any]
[any]
[any]

Based on this example, would we generalize or specialize?

● Generalize ○ Specialize

Visit2

restaurant : Kim's **meal** : Lunch **day** : Friday

cost : Cheap **vegan** : no

After generalizing, what will the general model be?

Visit3

restaurant : Sam's **meal** : Lunch **day** : Saturday

cost : Cheap **vegan** : no

Based on this example, would we generalize or specialize?

o Generalize ● Specialize

Visit3

restaurant : Sam's **meal** : Lunch **day** : Saturday

cost : Cheap **vegan** : no

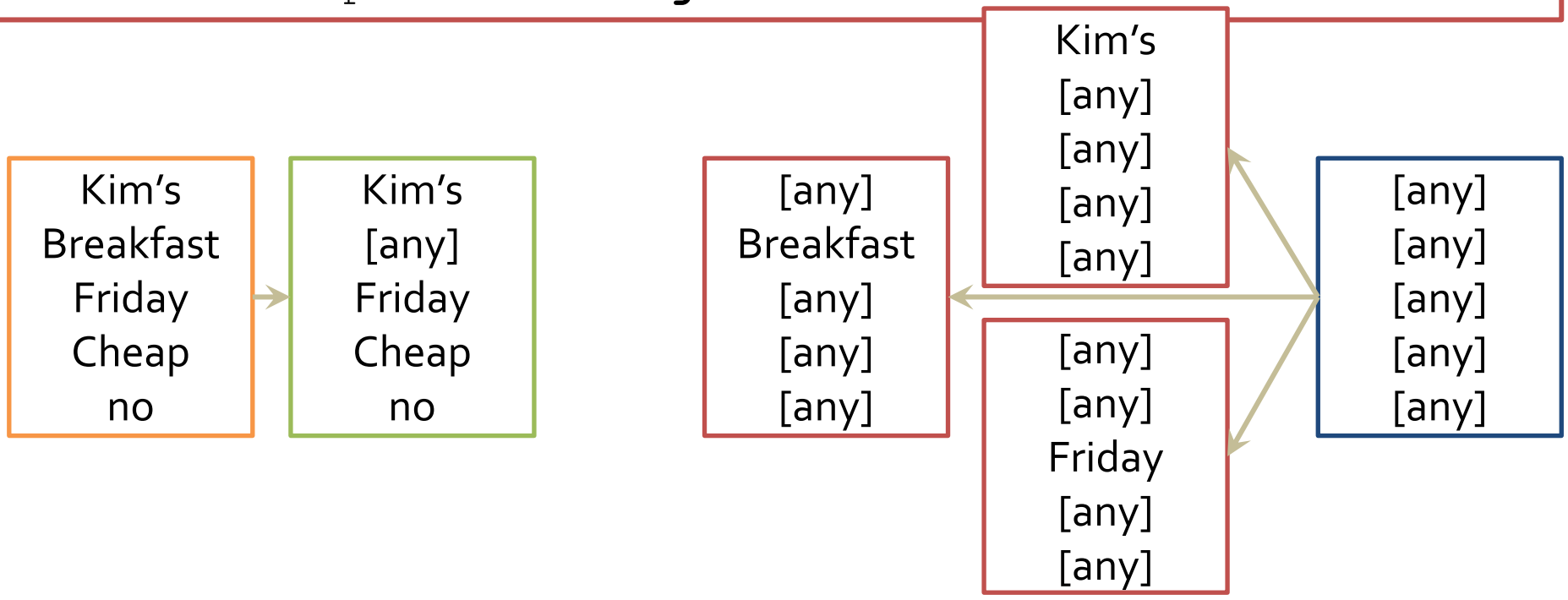
How many potential general models will we have after specializing based on this case and pruning?

3

Visit3

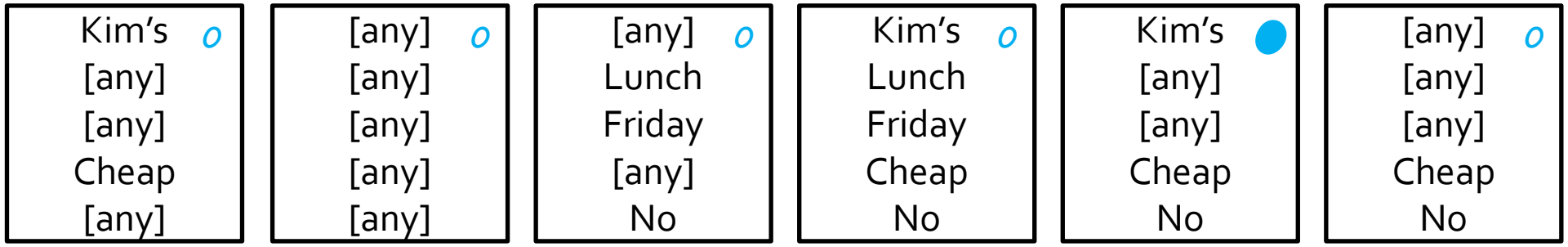
restaurant : Sam's **meal** : Lunch **day** : Saturday

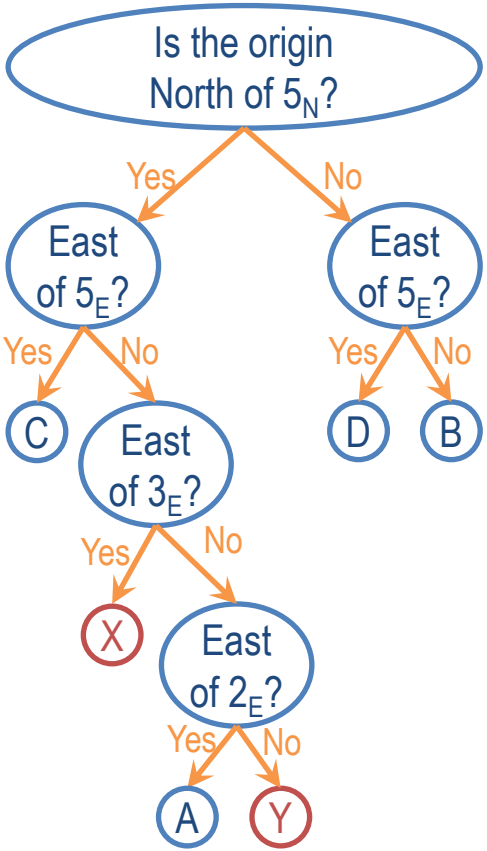
cost : Cheap **vegan** : no



Number	Meal	Meal	Day	Cost	Vegan	Reaction?
Visit1	Kim's	Breakfast	Friday	Cheap	No	Yes
Visit2	Kim's	Lunch	Friday	Cheap	No	Yes
Visit3	Sam's	Lunch	Saturday	Cheap	No	No
Visit4	Kim's	Breakfast	Sunday	Cheap	Yes	No
Visit5	Sam's	Breakfast	Sunday	Expensive	Yes	No
Visit6	Kim's	Lunch	Saturday	Cheap	No	Yes
Visit7	Kim's	Lunch	Monday	Expensive	No	No

What model did you converge on?

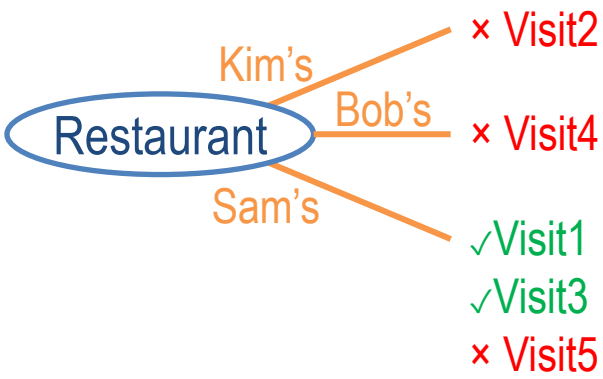



Is the origin North of 5_N?
Yes
No
East of 5_E?
East of 5_E?
Yes
No
Yes
No
C
East of 3_E?
D
B
Yes
No
X
East of 2_E?
Yes
No
A
Y

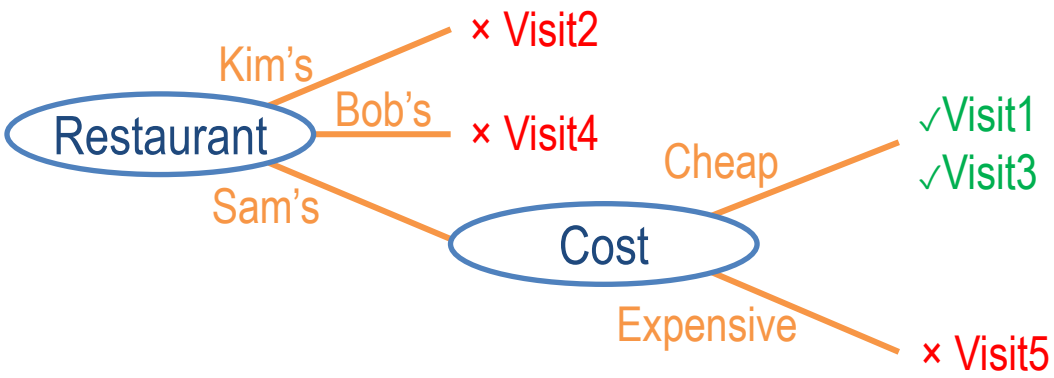

10_N
9_N
8_N
7_N
6_N
5_N
4_N
3_N
2_N
1_N
0_N
0_E
1_E
2_E
3_E
4_E
5_E
6_E
7_E
8_E
9_E
10_E
A
C
Y
X
D
B

Number	Restaurant	Meal	Day	Cost	Allergic Reaction?
Visit1	Sam's	Breakfast	Friday	Cheap	Yes
Visit2	Kim's	Lunch	Friday	Expensive	No
Visit3	Sam's	Lunch	Saturday	Cheap	Yes
Visit4	Bob's	Breakfast	Sunday	Cheap	No
Visit5	Sam's	Breakfast	Sunday	Expensive	No

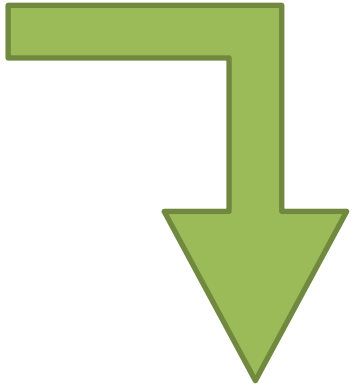
Number	Restaurant	Meal	Day	Cost	Allergic Reaction?
Visit1	Sam's	Breakfast	Friday	Cheap	Yes
Visit2	Kim's	Lunch	Friday	Expensive	No
Visit3	Sam's	Lunch	Saturday	Cheap	Yes
Visit4	Bob's	Breakfast	Sunday	Cheap	No
Visit5	Sam's	Breakfast	Sunday	Expensive	No



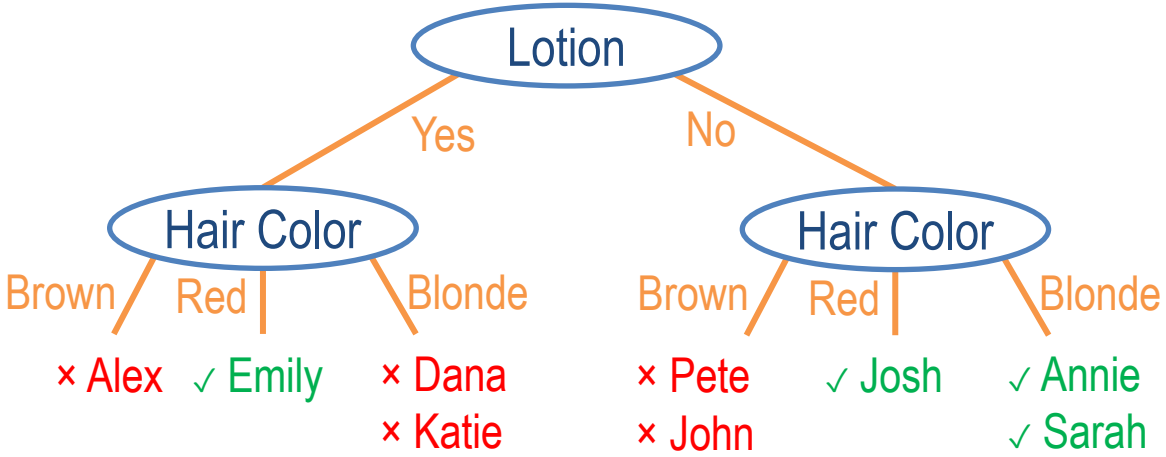
Number	Restaurant	Meal	Day	Cost	Allergic Reaction?
Visit1	Sam's	Breakfast	Friday	Cheap	Yes
Visit2	Kim's	Lunch	Friday	Expensive	No
Visit3	Sam's	Lunch	Saturday	Cheap	Yes
Visit4	Bob's	Breakfast	Sunday	Cheap	No
Visit5	Sam's	Breakfast	Sunday	Expensive	No



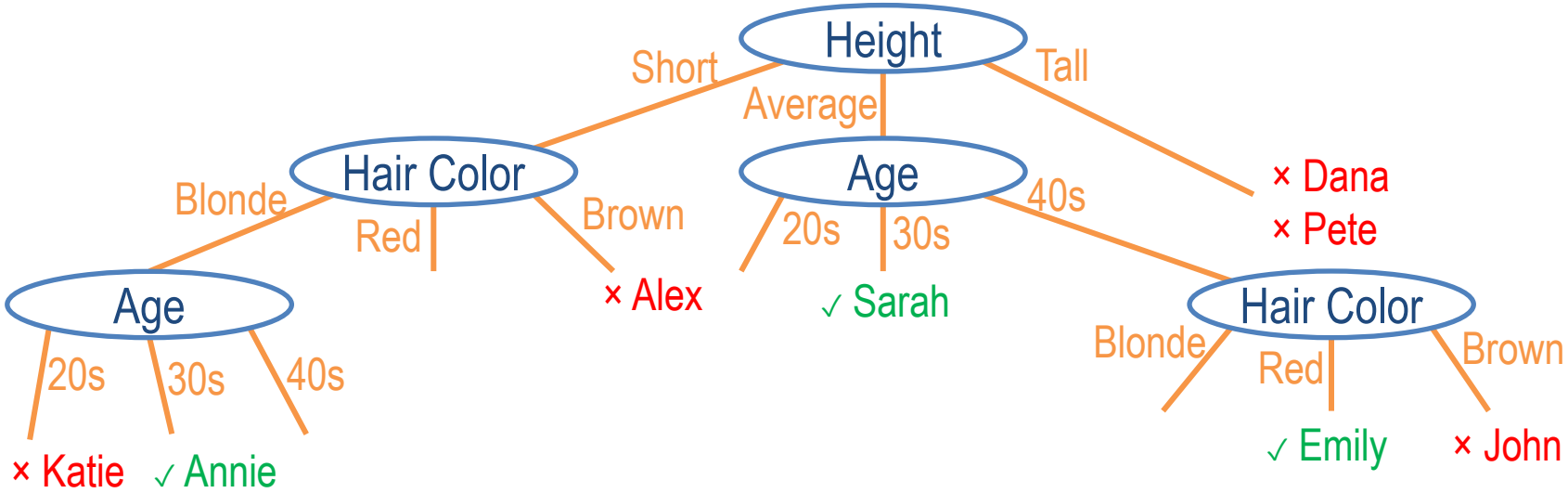
Name	Hair	Height	Age	Lotion	Burn?
Sarah	Blonde	Average	20s	No	Yes
Dana	Blonde	Tall	30s	Yes	No
Alex	Brown	Short	30s	Yes	No
Annie	Blonde	Short	30s	No	Yes
Emily	Red	Average	40s	Yes	Yes
Pete	Brown	Tall	40s	No	No
John	Brown	Average	40s	No	No
Katie	Blonde	Short	20s	Yes	No
Josh	Red	Short	20s	No	Yes




Hair Color
Brown
Red
Blonde
Lotion
Lotion
Yes
No
Yes
No
× Alex
× Pete
× John
✓ Emily
✓ Josh
× Dana
× Katie
✓ Annie
✓ Sarah


Lotion
Yes
No
Hair Color
Hair Color
Brown
Red
Blonde
Brown
Red
Blonde
× Alex
✓ Emily
× Dana
× Katie
× Pete
× John
✓ Josh
✓ Annie
✓ Sarah


Hair Color
Brown
Red
Blonde
Lotion
Lotion
Yes
No
Yes
No
× Alex
× Pete
× John
✓ Emily
✓ Josh
× Dana
× Katie
✓ Annie
✓ Sarah


Height
Short
Average
Tall
Hair Color
Age
× Dana
× Pete
Blonde
Red
Brown
20s
30s
40s
Age
× Alex
✓ Sarah
Hair Color
20s
30s
40s
Blonde
Red
Brown
× Katie
✓ Annie
✓ Emily
× John

Assignment

How would you use version spaces to design an agent that could answer Raven's progressive matrices?

To recap…

- Definition of version spaces
- Algorithm for version spaces
- Complex problems with version spaces
- Limitations and questions
- Identification trees