04-05-2023

CS051A

INTRO TO COMPUTER SCIENCE WITH TOPICS IN AI

19: Informed search

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she/her/hers

Lectures

Zilong Ye

he/him/his

Labs

TODAY'S LECTURE IN A NUTSHELL

Lecture 19: Informed search

- Foxes and chickens
- Search problems
- Informed search

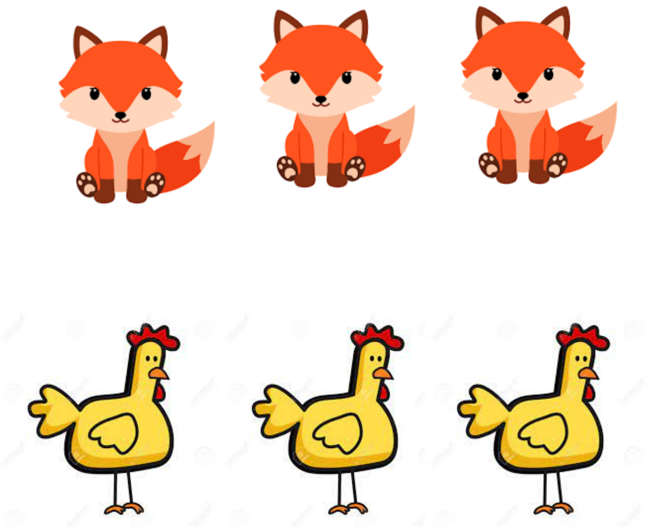
Foxes and Chickens

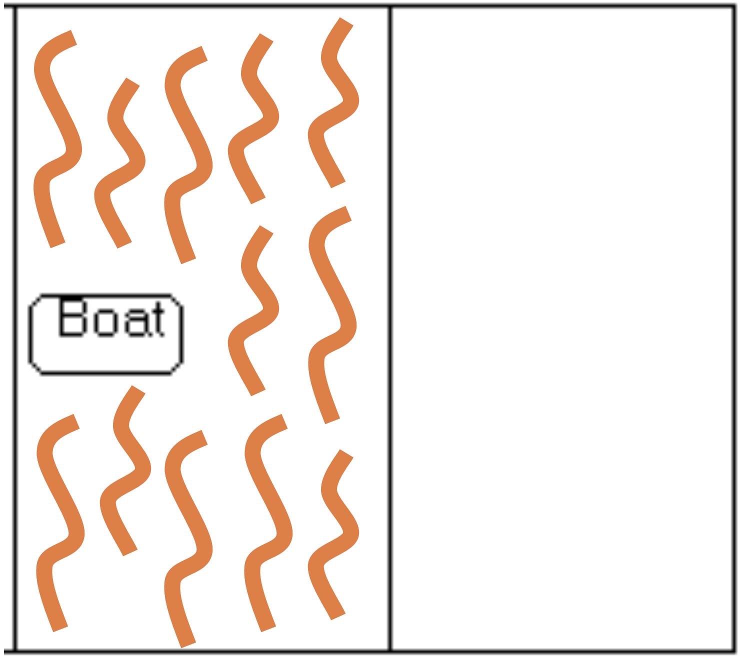
Three foxes and three chickens wish to cross the river. They have a small boat that will carry up to two animals. Everyone can navigate the boat. If at any time the foxes outnumber the chickens on either bank of the river, they will eat the chickens. Find the smallest number of crossings that will allow everyone to cross the river safely.

What is the "state" of this problem
(it should capture all possible valid configurations)?

Foxes and Chickens

Three foxes and three chickens wish to cross the river. They have a small boat that will carry up to two animals. Everyone can navigate the boat. If at any time the foxes outnumber the chickens on either bank of the river, they will eat the chickens. Find the smallest number of crossings that will allow everyone to cross the river safely.





Foxes and Chickens

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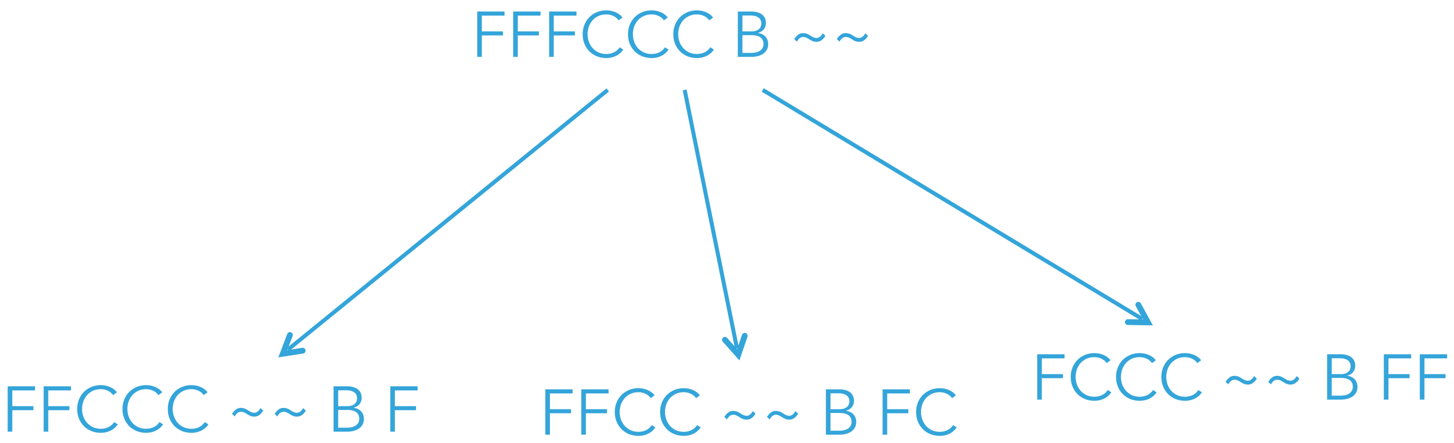
FFFCCC B	
FFCC	B FC
FC	B FFCC
. . .	

Searching for a solution

FFFCCC B ~~

What states can we get to from here?

Searching for a solution



FFFCCC B ~ ~

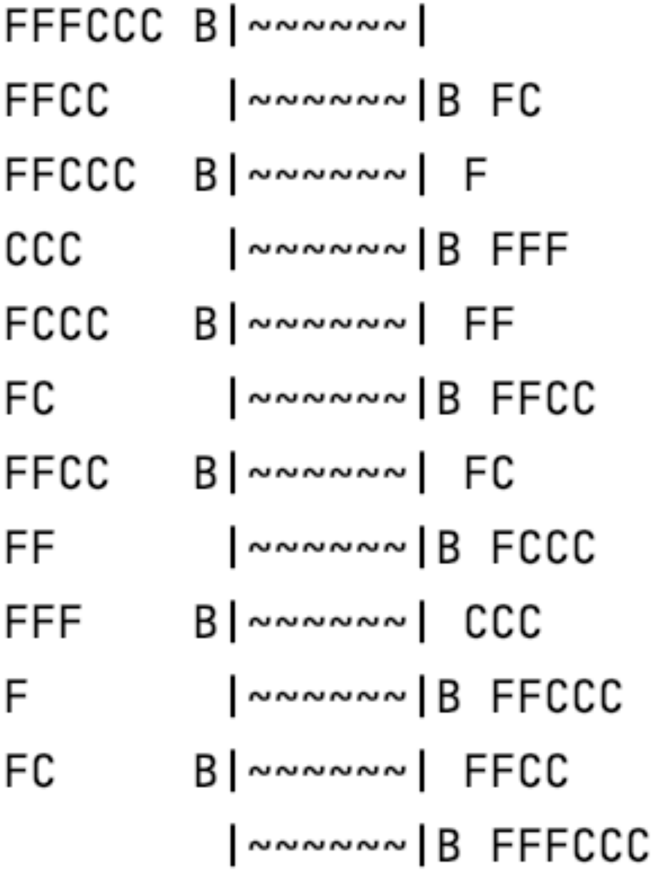
FFCCC ~ ~ B F

FFCC ~ ~ B FC

FCCC ~ ~ B FF

Next states?

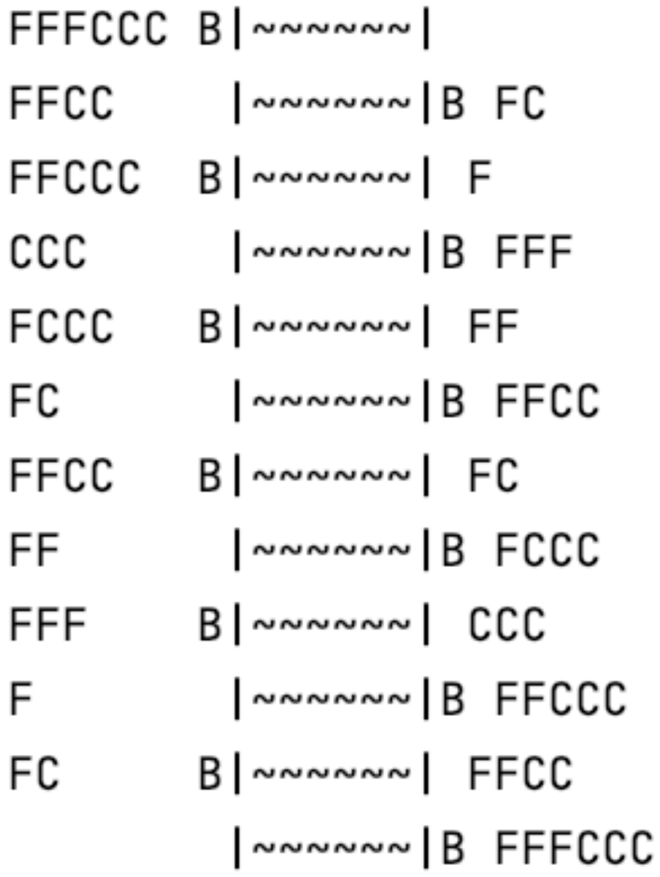
Fox and Chickens Solution



```
FFFCCC B|~~~~~~|
FFCC    |~~~~~~|B FC
FFCCC  B|~~~~~~| F
CCC     |~~~~~~|B FFF
FCCC   B|~~~~~~| FF
FC      |~~~~~~|B FFCC
FFCC   B|~~~~~~| FC
FF      |~~~~~~|B FCCC
FFF    B|~~~~~~| CCC
F       |~~~~~~|B FFCCC
FC     B|~~~~~~| FFCC
        |~~~~~~|B FFFCCC
```

How is this solution different than the n-queens problem?

Fox and Chickens Solution



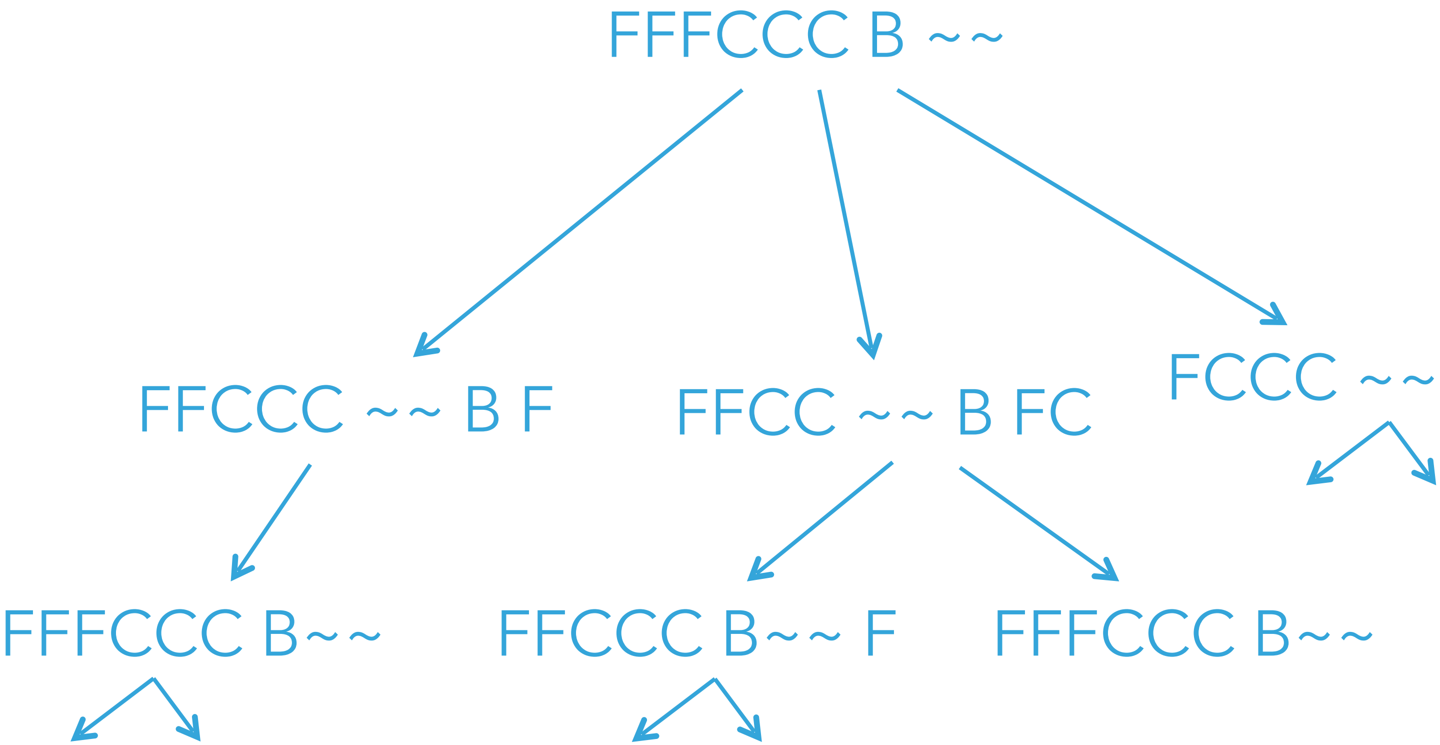
```
FFFCCC B|~~~~~~|
FFCC    |~~~~~~|B FC
FFCCC  B|~~~~~~| F
CCC     |~~~~~~|B FFF
FCCC   B|~~~~~~| FF
FC      |~~~~~~|B FFCC
FFCC   B|~~~~~~| FC
FF      |~~~~~~|B FCCC
FFF    B|~~~~~~| CCC
F       |~~~~~~|B FFCCC
FC     B|~~~~~~| FFCC
        |~~~~~~|B FFFCCC
```

Solution is not a state, but a sequence of actions (or a sequence of states)

`chickens.py`

- Look at the code that solves the foxes and chickens problem.

One other problem



FFFCCC B ~~

FFCCC ~~ B F

FFCC ~~ B FC

FCCC ~~ B FF

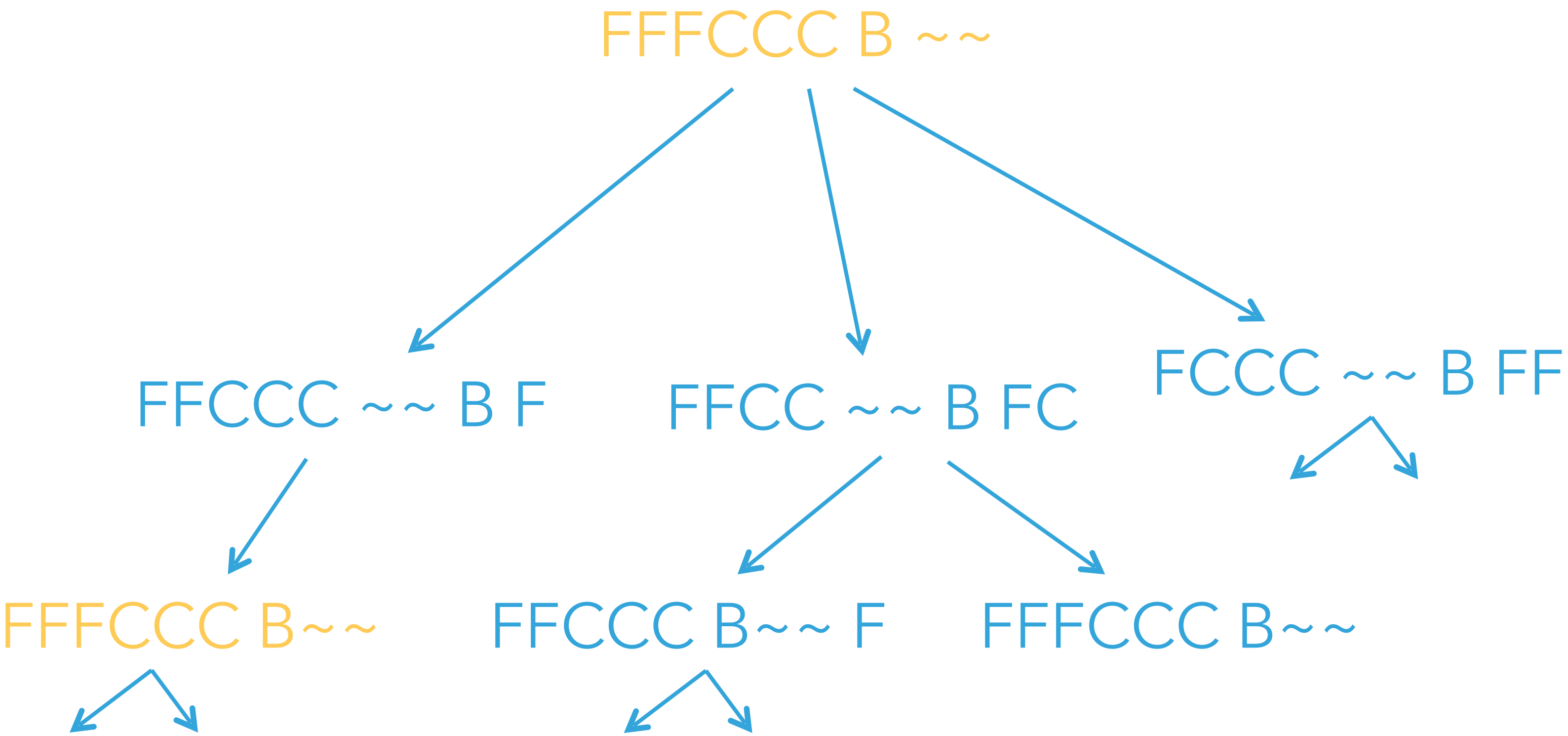
FFFCCC B~~

FFCCC B~~ F

FFFCCC B~~

What would happen if we ran DFS here?

One other problem



FFFCCC B ~~

FFCCC ~~ B F

FFCC ~~ B FC

FCCC ~~ B FF

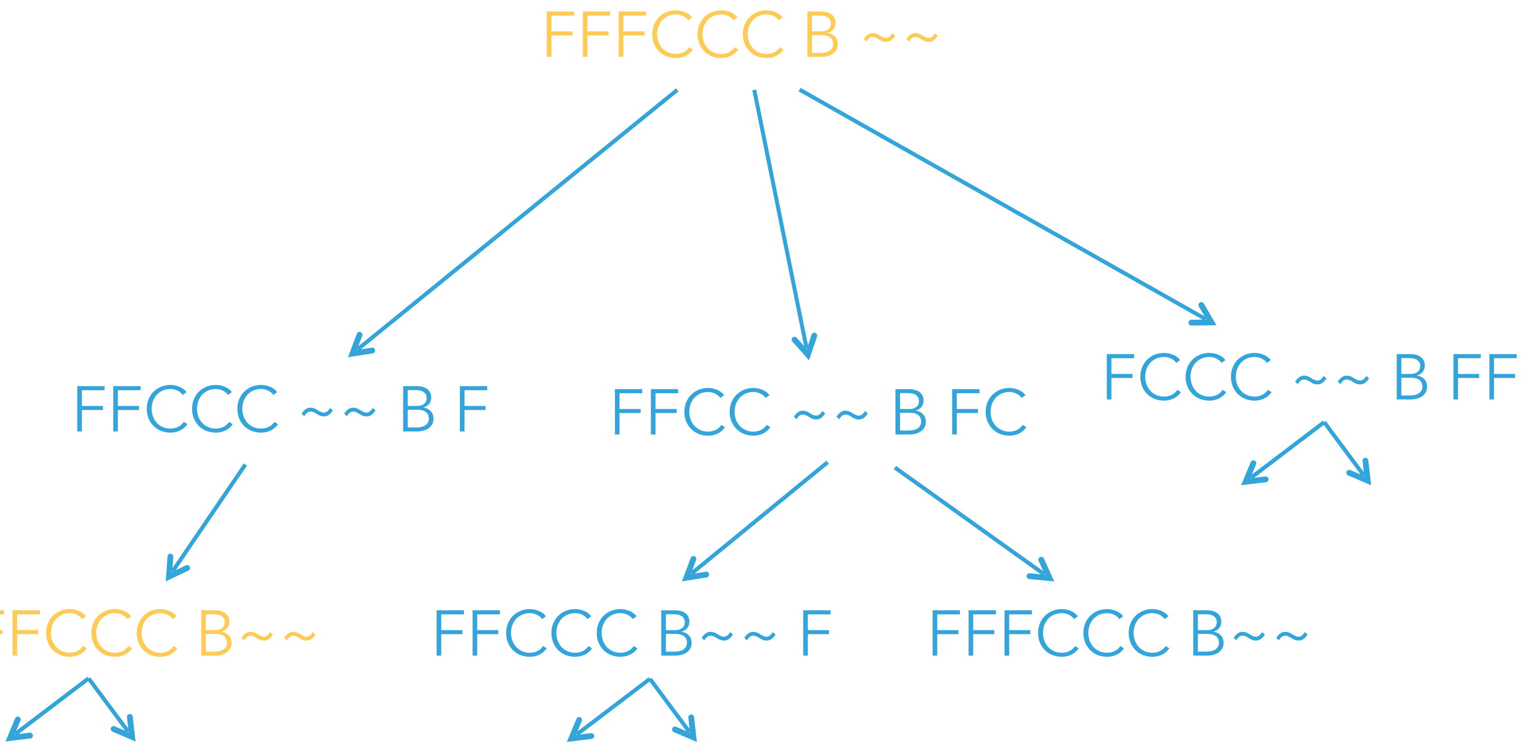
FFFCCC B~~

FFCCC B~~ F

FFFCCC B~~

If we always go left first, will continue forever!

One other problem



FFFCCC B ~ ~

FFCCC ~ ~ B F

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FCCC ~ ~ B FF

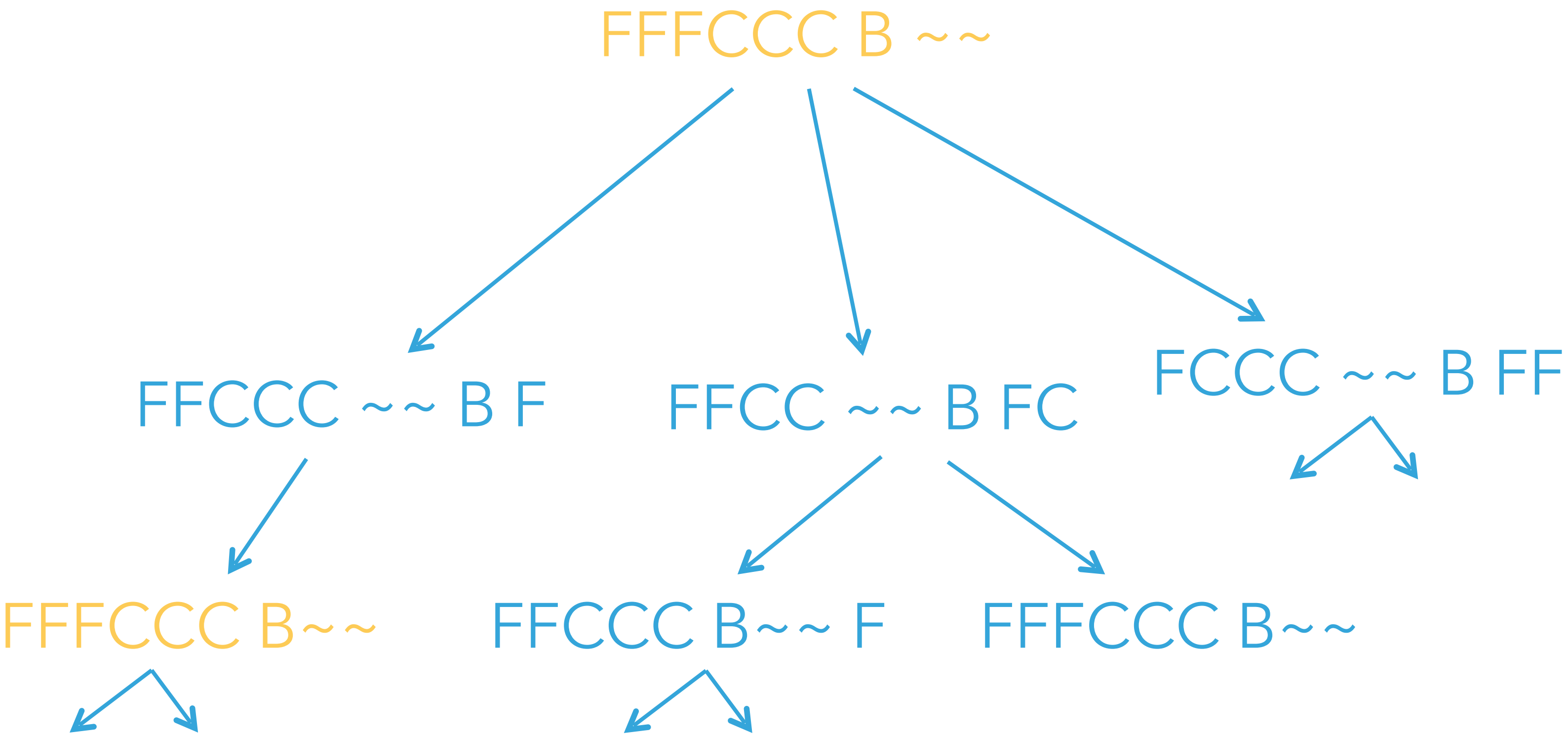
FFFCCC B ~ ~

FFCCC B ~ ~ F

FFFCCC B ~ ~

Does BFS have this problem?

One other problem



FFFCCC B ~~

FFCCC ~~ B F

FFCC ~~ B FC

FCCC ~~ B FF

FFFCCC B~~

FFCCC B~~ F

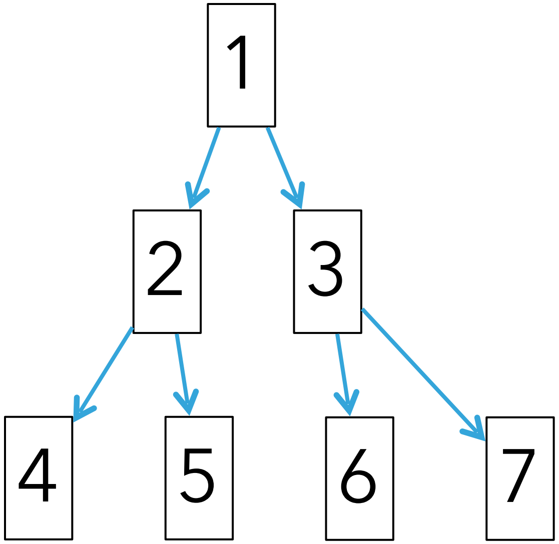
FFFCCC B~~

No!

DFS vs. BFS

- Why do we use DFS then, and not BFS?

DFS vs. BFS

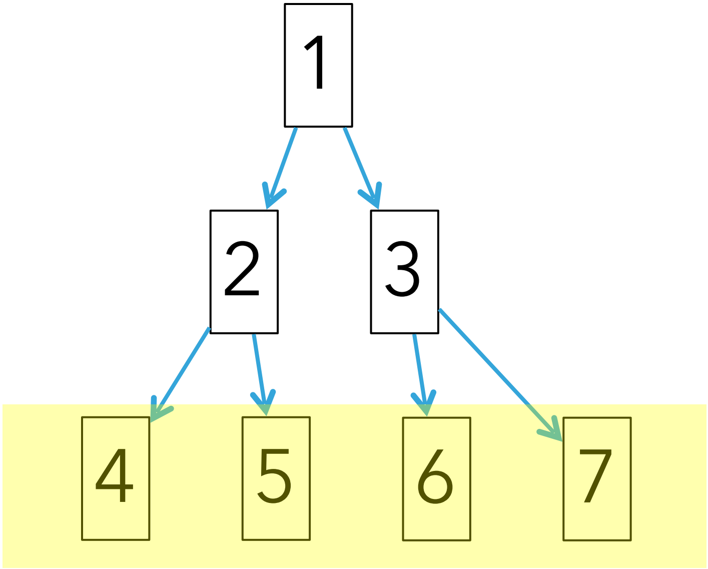


Consider a search problem where each state has two states you can reach

Assume the goal state involves 20 actions, i.e. moving between ~20 states

How big can the queue get for BFS?

DFS vs. BFS

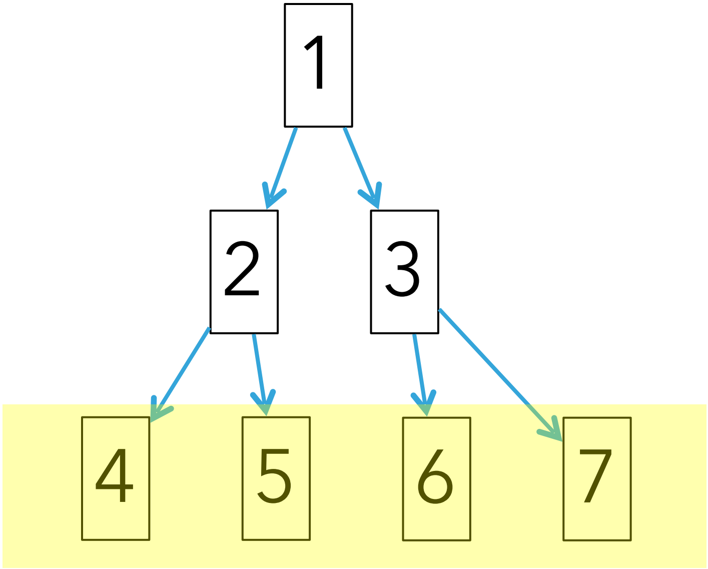


Consider a search problem where each state has two states you can reach

Assume the goal state involves 20 actions, i.e. moving between ~20 states

At any point, need to remember roughly a level

DFS vs. BFS

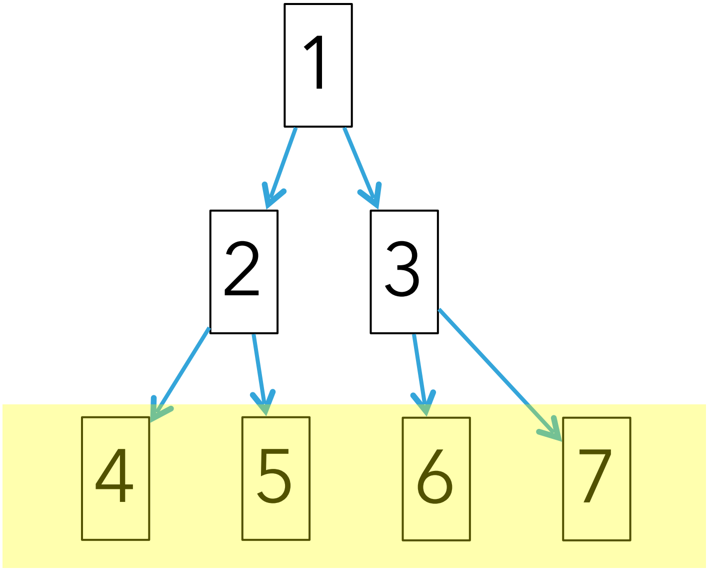


Consider a search problem where each state has two states you can reach

Assume the goal state involves 20 actions, i.e. moving between ~20 states

How big does this get?

DFS vs. BFS



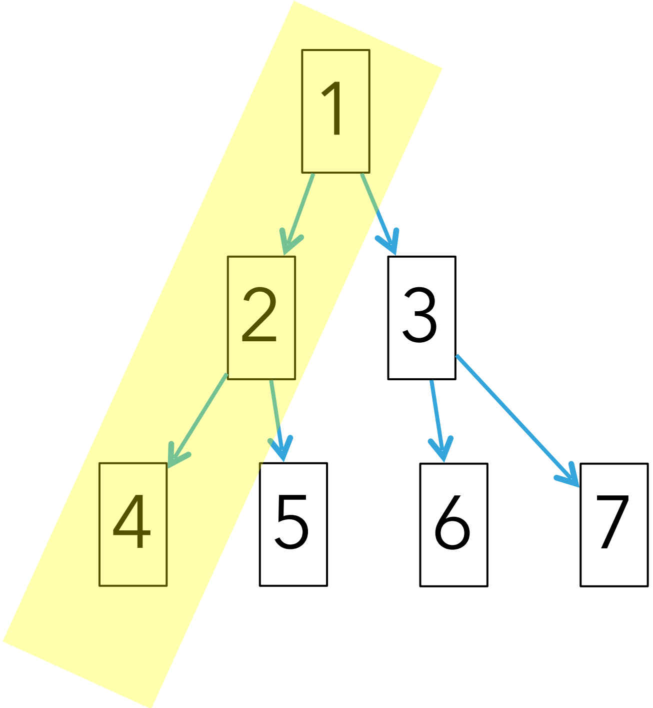
Consider a search problem where each state has two states you can reach

Assume the goal state involves 20 actions, i.e. moving between ~20 states

Doubles every level we have to go deeper.

For 20 actions that is 2^{20} = ~1 million states!

DFS vs. BFS

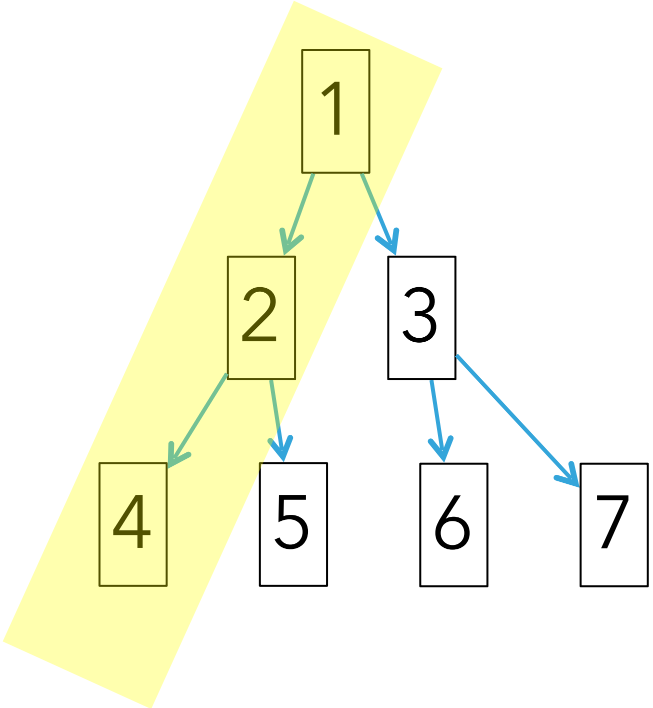


Consider a search problem where each state has two states you can reach

Assume the goal state involves 20 actions, i.e. moving between ~20 states

How many states would DFS keep on the stack?

DFS vs. BFS

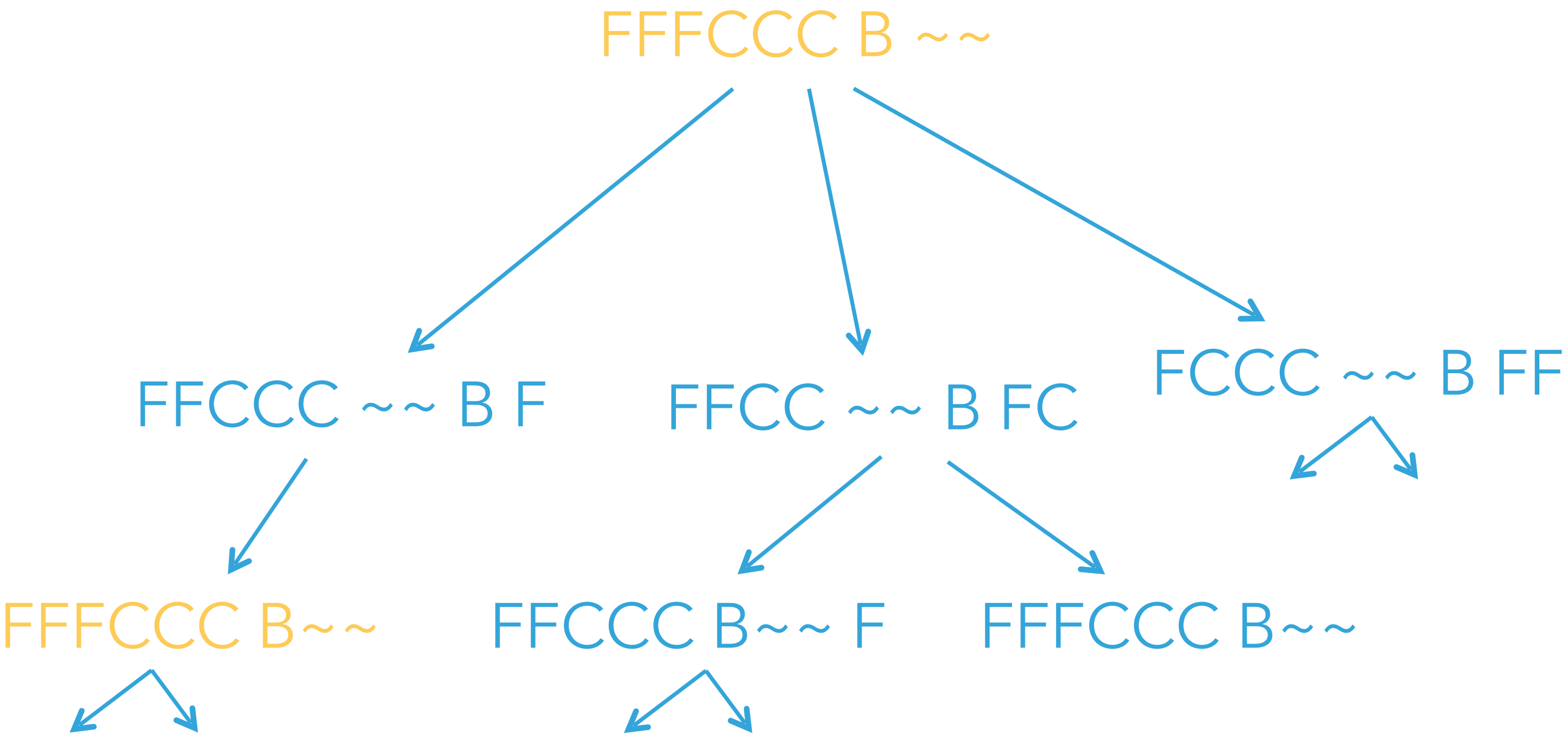


Consider a search problem where each state has two states you can reach

Assume the goal state involves 20 actions, i.e. moving between ~20 states

Only one path through the tree, roughly 20 states

One other problem



FFFCCC B ~~

FFCCC ~~ B F

FFCC ~~ B FC

FCCC ~~ B FF

FFFCCC B~~

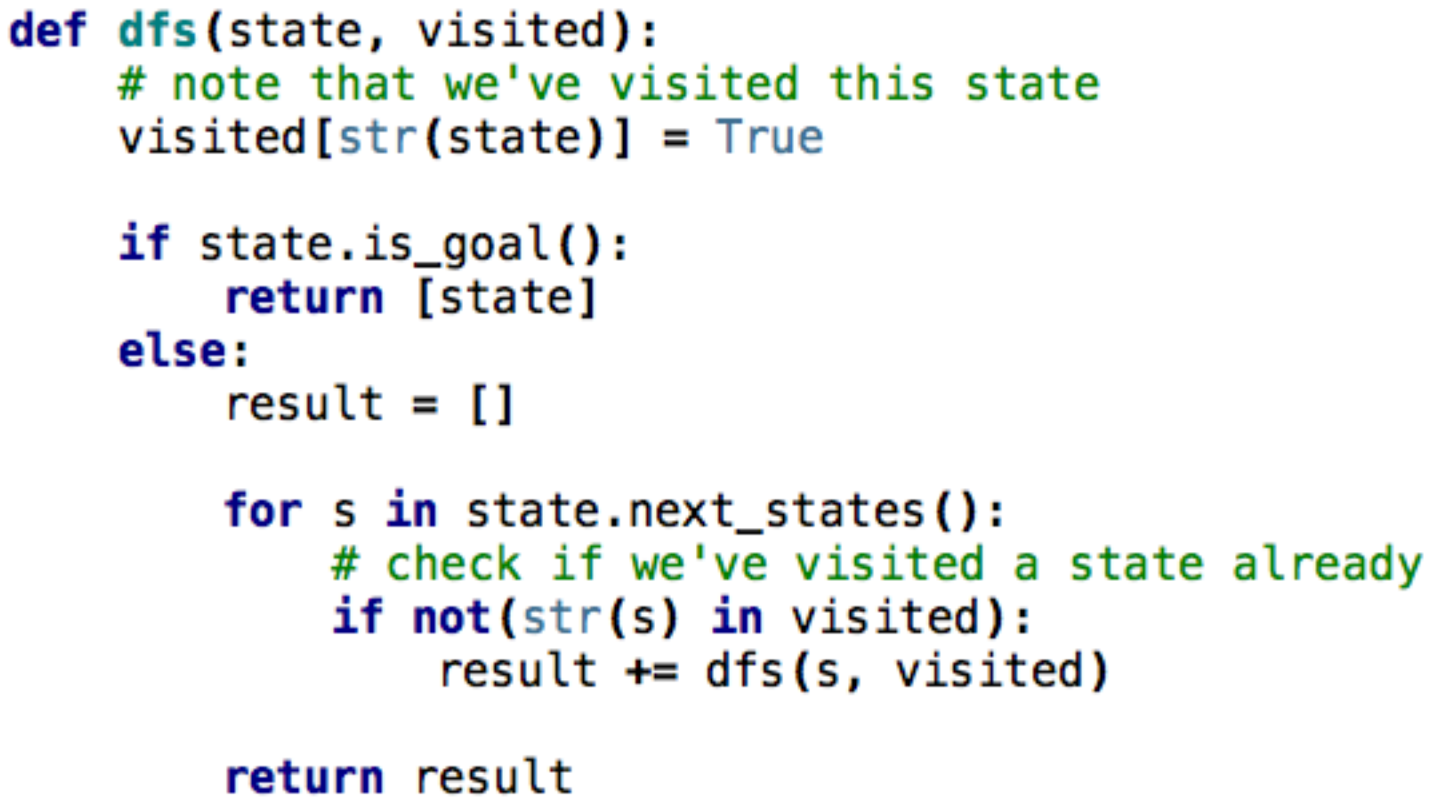
FFCCC B~~ F

FFFCCC B~~

If we always go left first, will continue forever!

Solution?

DFS avoiding repeats



```python
def dfs(state, visited):
    # note that we've visited this state
    visited[str(state)] = True

    if state.is_goal():
        return [state]
    else:
        result = []

        for s in state.next_states():
            # check if we've visited a state already
            if not(str(s) in visited):
                result += dfs(s, visited)

        return result
```

TODAY'S LECTURE IN A NUTSHELL

Lecture 19: Informed search

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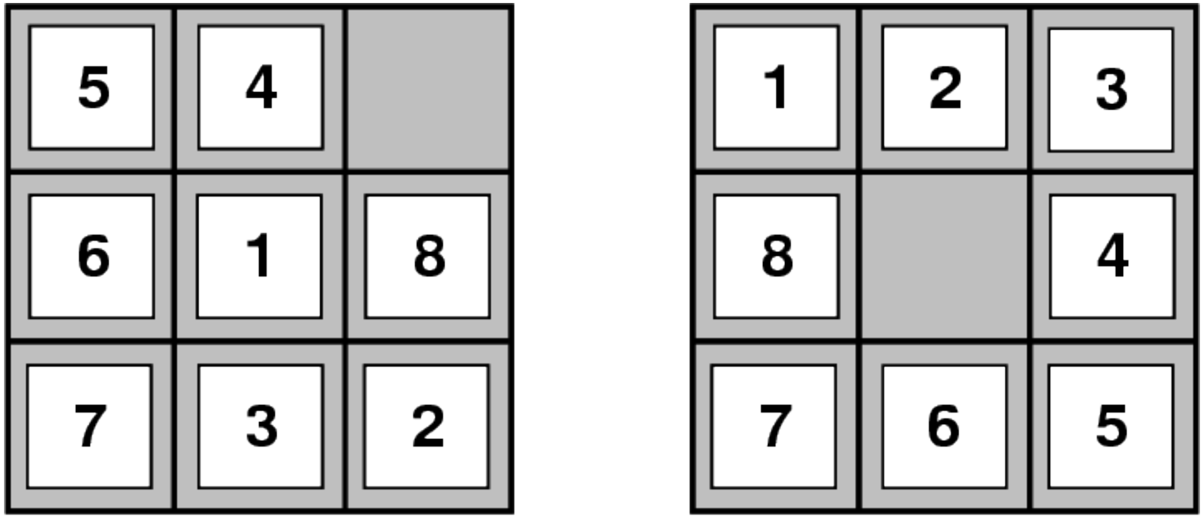
Other search problems

What problems have you seen that could be posed as search problems by defining:

- What is the state
- Start state
- Goal state
- State-space/transition between states

8-puzzle



5	4	
6	1	8
7	3	2

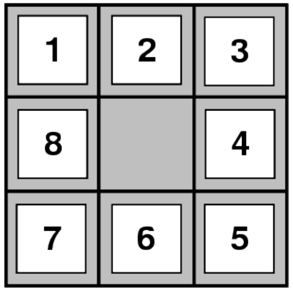
Start State

1	2	3
8		4
7	6	5

Goal State

8-puzzle

- goal



1	2	3
8		4
7	6	5

Goal State

- state representation?
- start state?
- state-space/transitions?

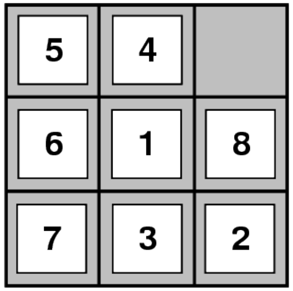
8-puzzle

state:

- all 3 x 3 configurations of the tiles on the board

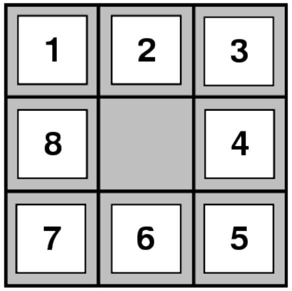
transitions between states:

- Move Blank Square Left, Right, Up or Down.
- This is a more efficient encoding than moving each of the 8 distinct tiles



5	4	
6	1	8
7	3	2

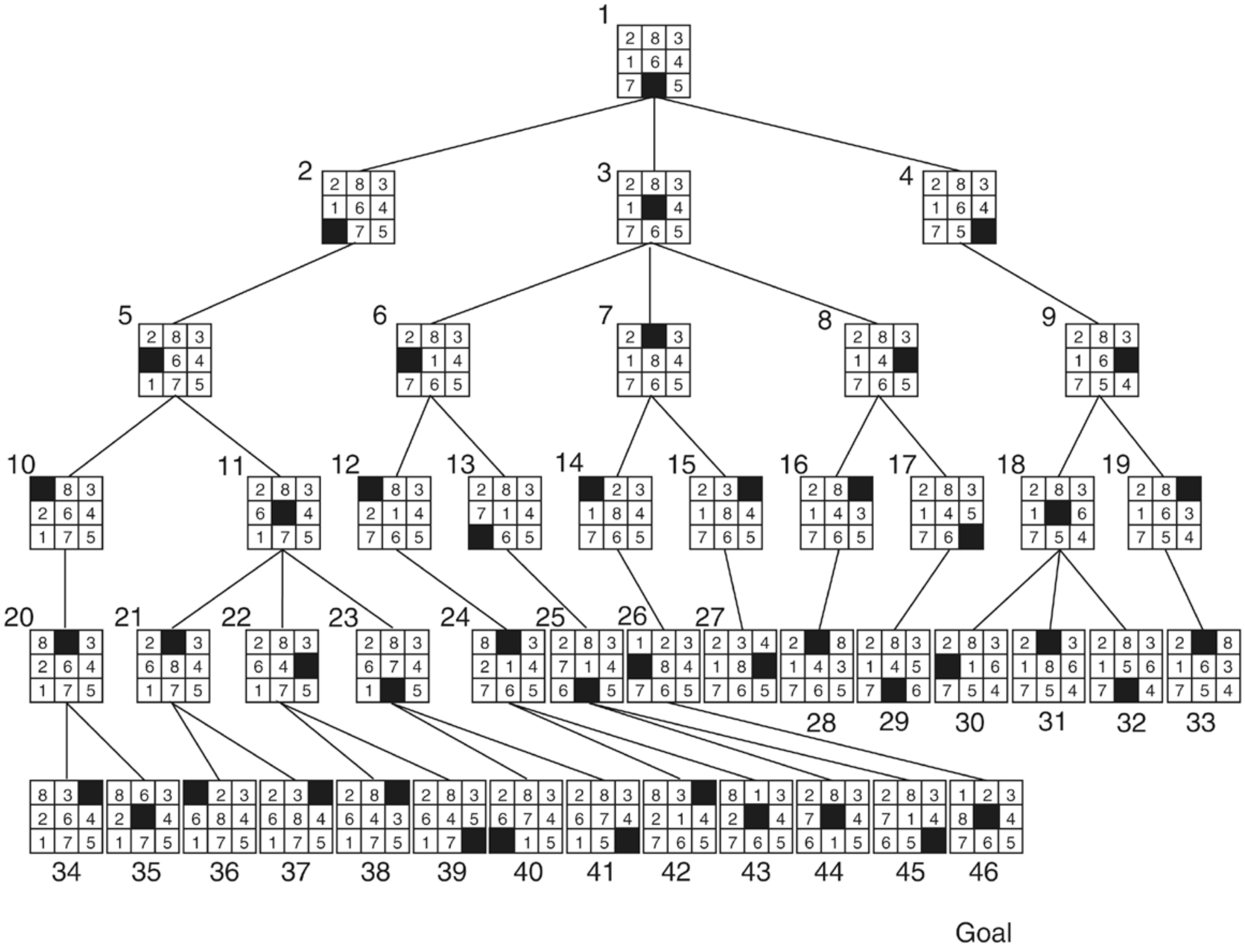
Start State



1	2	3
8		4
7	6	5

Goal State

8-puzzle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46
Goal

Cryptarithmetic

Find an assignment of digits (0, …, 9) to letters so that a given arithmetic expression is true. examples:

SEND + MORE = MONEY

```
 FORTY
+  TEN
+  TEN
 -----
 SIXTY
F=2, O=9, R=7, etc.
```

Cryptarithmetic

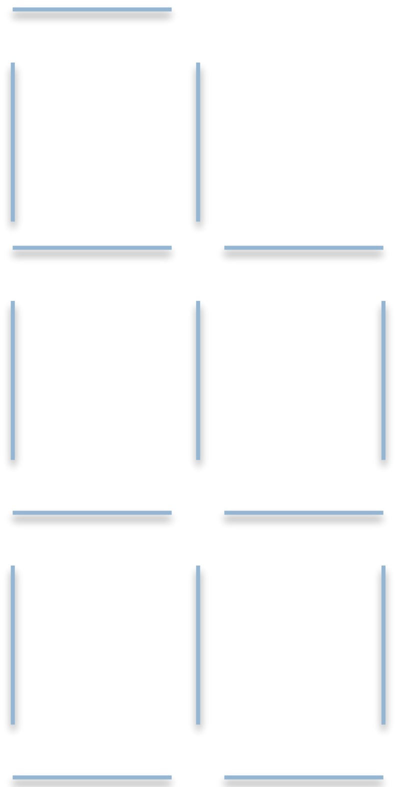
Find an assignment of digits (0, ..., 9) to letters so that a given arithmetic expression is true. examples:

SEND + MORE = MONEY

```
  FORTY      Solution:   29786
+   TEN                    850
+   TEN                    850
  -----                  -----
  SIXTY                  31486
F=2, O=9, R=7, etc.
```

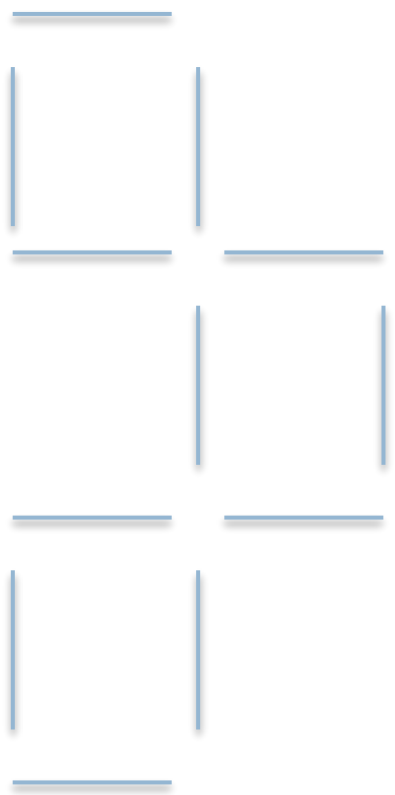
Remove 3 match sticks

- Given the following configuration of sticks, remove exactly 3 sticks in such a way that the remaining configuration forms exactly 3 squares.



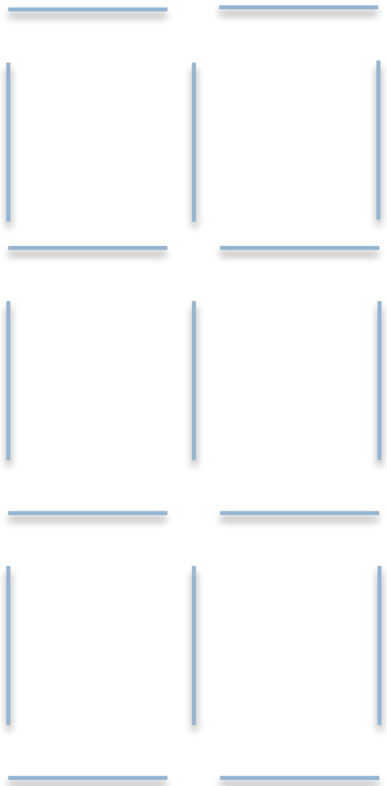
Remove 3 match sticks

- Given the following configuration of sticks, remove exactly 3 sticks in such a way that the remaining configuration forms exactly 3 squares.



Remove 5 match sticks

- Given the following configuration of sticks, remove exactly 5 sticks in such a way that the remaining configuration forms exactly 3 squares.



Remove 5 match sticks

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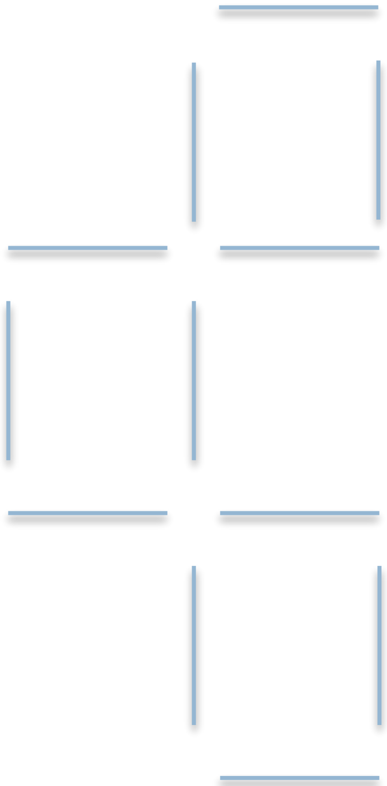

Water Jug Problem

- Given a full 5-gallon jug and a full 2-gallon jug, fill the 2-gallon jug with exactly one gallon of water.

Operator table

Name	Cond.	Transition	Effect
Empty5	–	(x,y)→(0,y)	Empty 5-gal. jug
Empty2	–	(x,y)→(x,0)	Empty 2-gal. jug
2to5	x ≤ 3	(x,2)→(x+2,0)	Pour 2-gal. into 5-gal.
5to2	x ≥ 2	(x,0)→(x-2,2)	Pour 5-gal. into 2-gal.
5to2part	y < 2	(1,y)→(0,y+1)	Pour partial 5-gal. into 2-gal.

8-puzzle revisited

- How hard is this problem?

1	3	8
4		7
6	5	2

8-puzzle revisited

- The average depth of a solution for an 8-puzzle is 22 moves
- An exhaustive search requires searching ~3^{22} states
    - BFS: 10 terabytes of memory
    - DFS: 8 hours (assuming one million nodes/second)
- Can we do better?
- Is DFS and BFS intelligent?

1	3	8
4		7
6	5	2

TODAY'S LECTURE IN A NUTSHELL

Lecture 19: Informed search

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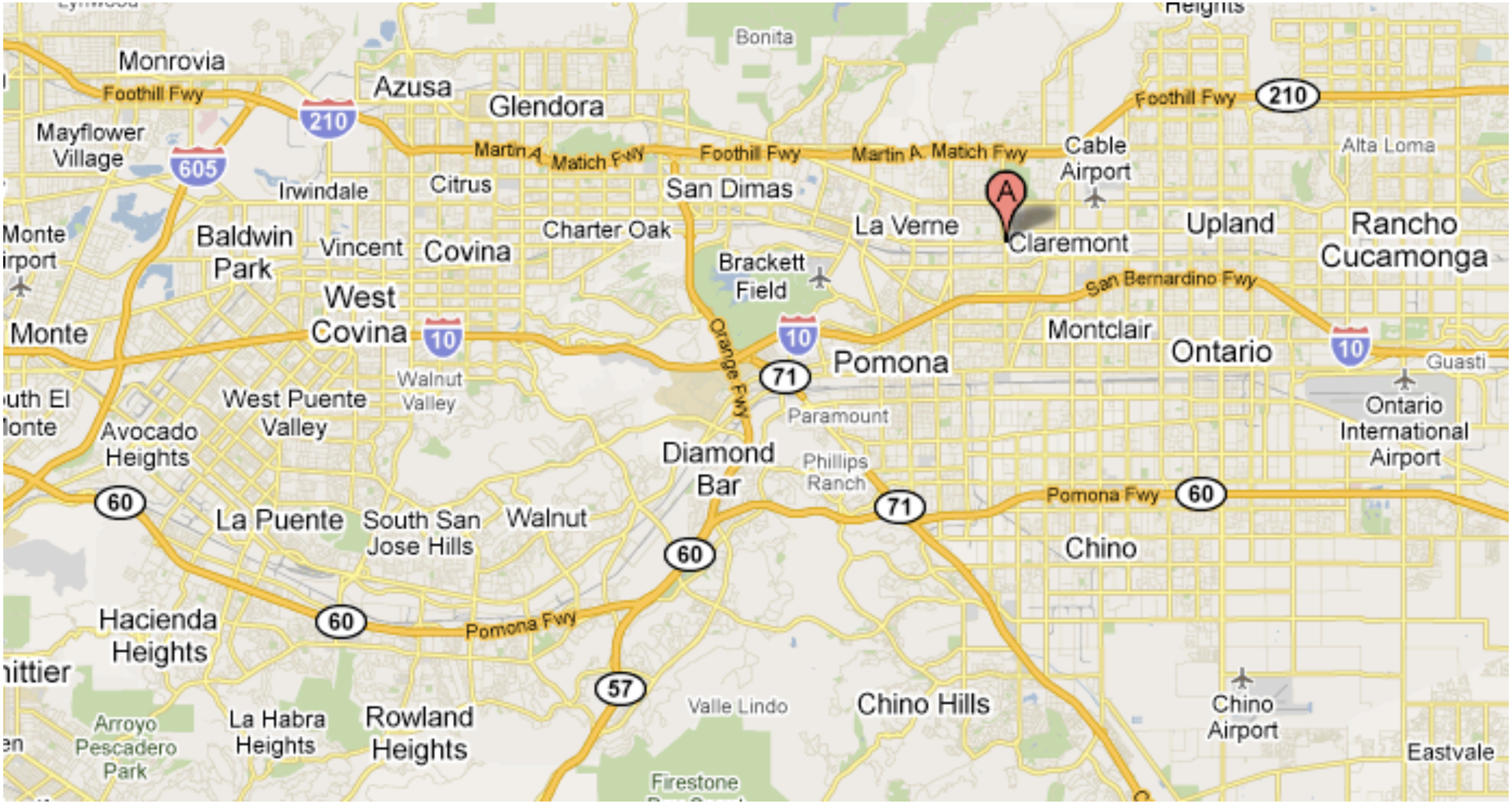
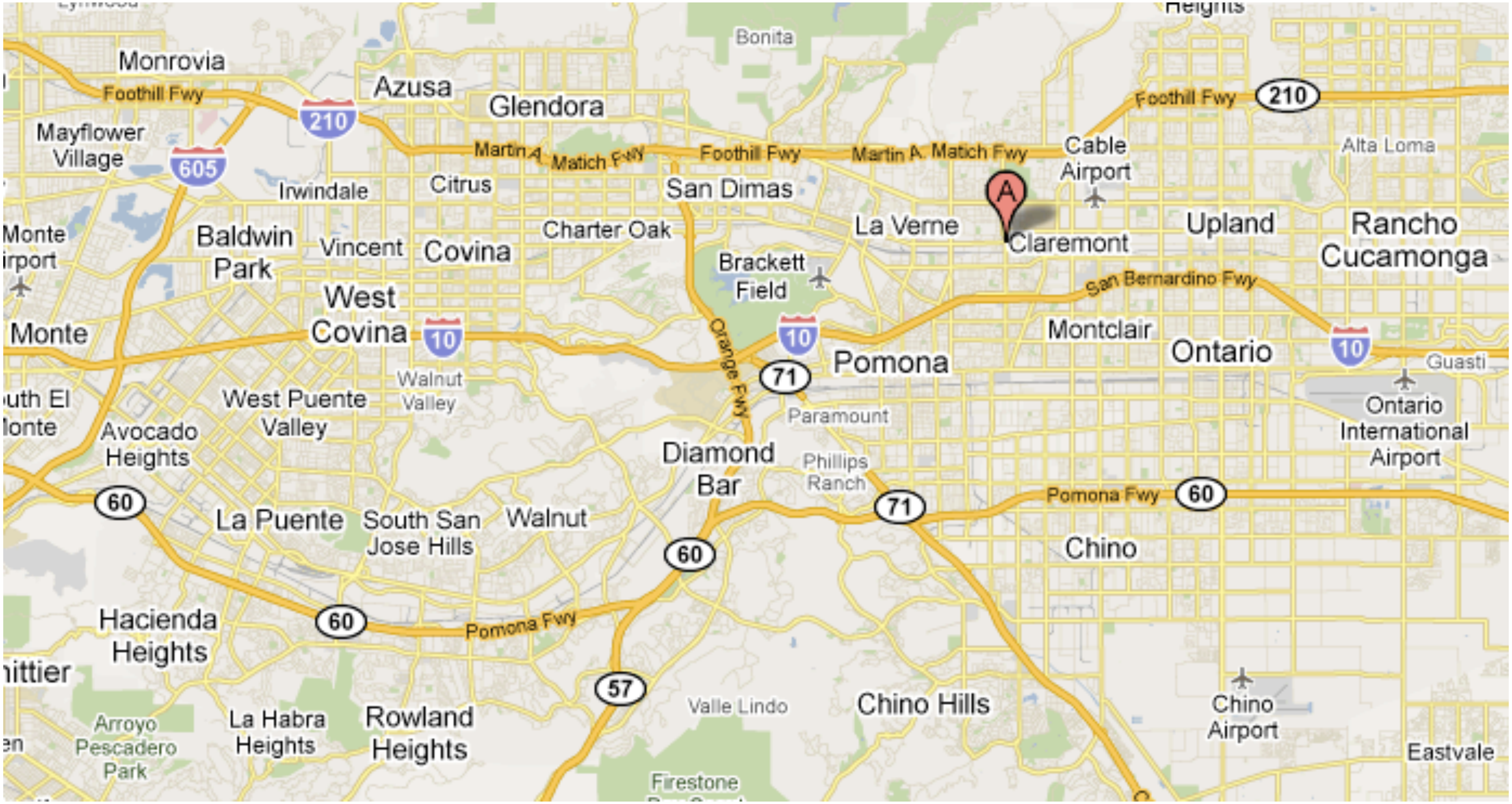
How do you think google maps does it?

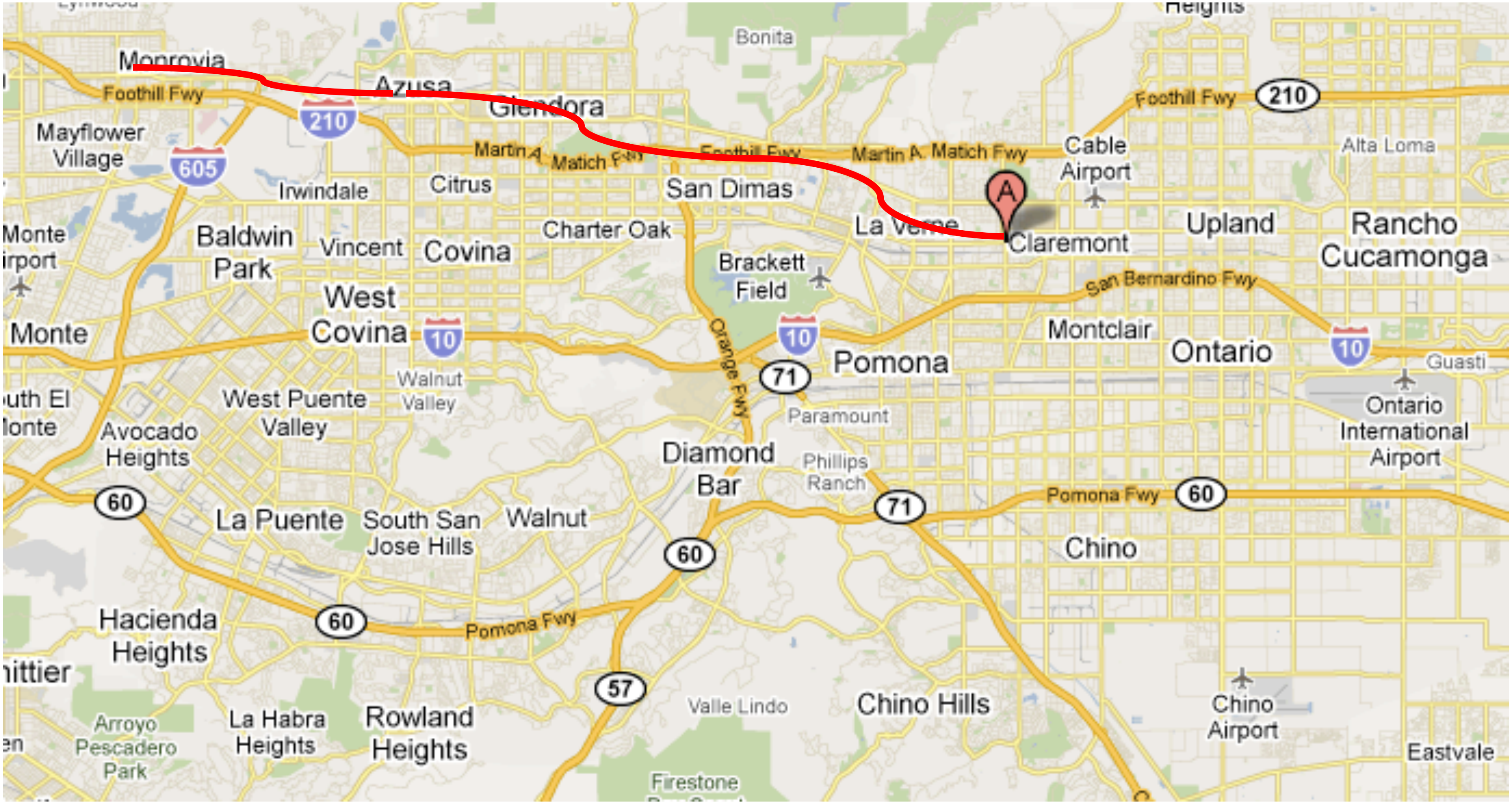


INFORMED SEARCH

What would the search algorithms do?



DFS


Monrovia
Foothill Fwy
Azusa
Glendora
210
Mayflower Village
605
Irwindale
Citrus
Martin A. Match Fwy
Foothill Fwy
Martin A. Match Fwy
San Dimas
Cable Airport
A
Claremont
Foothill Fwy
210
Alta Loma
Upland
Rancho Cucamonga
Bonita
Monte
irport
Baldwin Park
Vincent
Covina
Charter Oak
La Verne
Brackett Field
San Bernardino Fwy
West Covina
10
Monte
10
Pomona
Montclair
Ontario
10
Guasti
71
Walnut Valley
Orange Fwy
uth El Monte
West Puente Valley
Avocado Heights
Paramount
Ontario International Airport
Diamond Bar
Phillips Ranch
60
La Puente
South San Jose Hills
Walnut
60
71
Pomona Fwy
60
Chino
Hacienda Heights
60
Pomona Fwy
57
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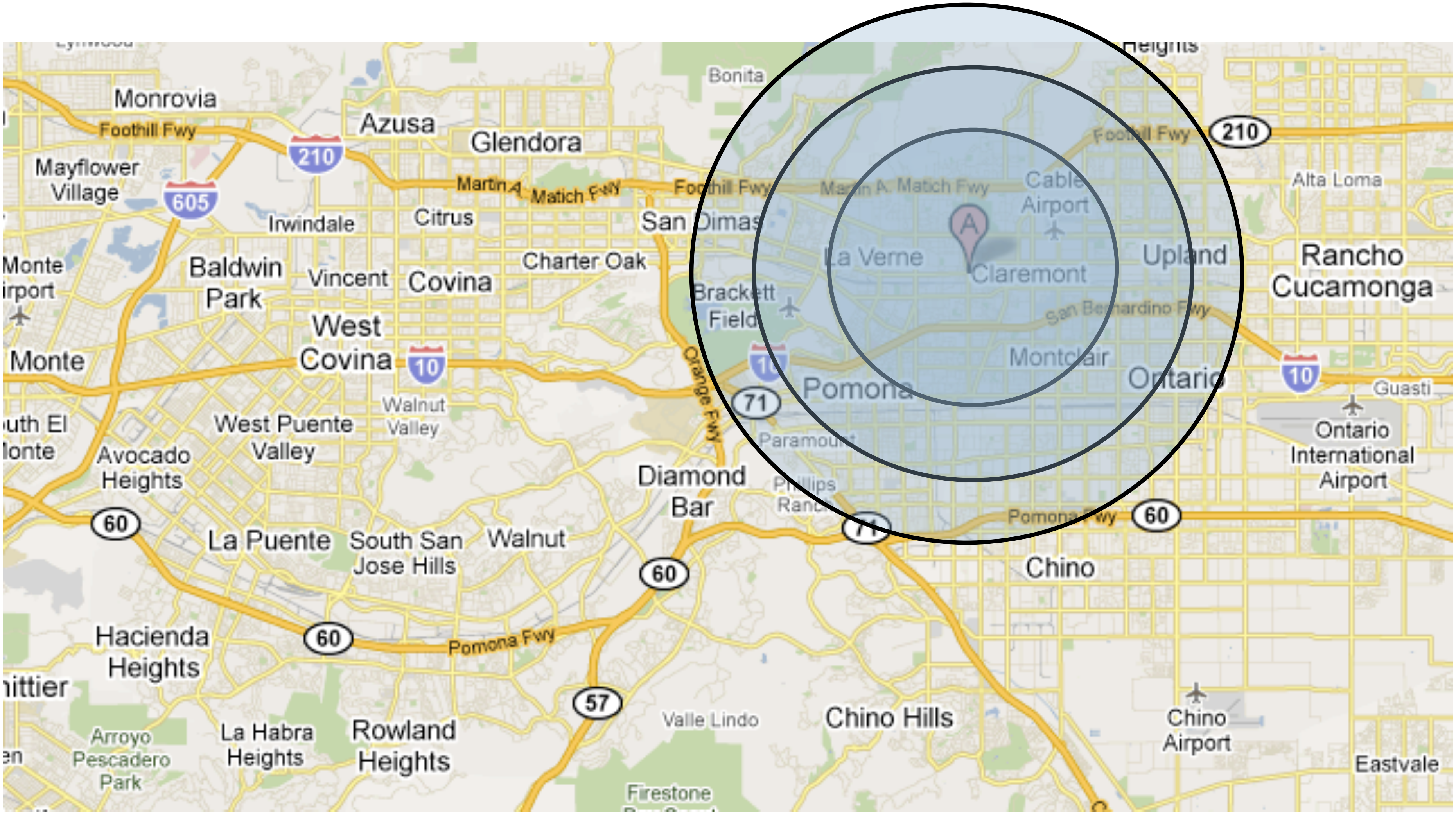
Valle Lindo
Chino Hills
Chino Airport
Arroyo Pescadero Park
La Habra Heights
Rowland Heights
Firestone
Eastvale
en

BFS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Upland
Rancho Cucamonga
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Baldwin Park
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Diamond Bar
Phillips Ranch
Ontario International Airport
Guasti
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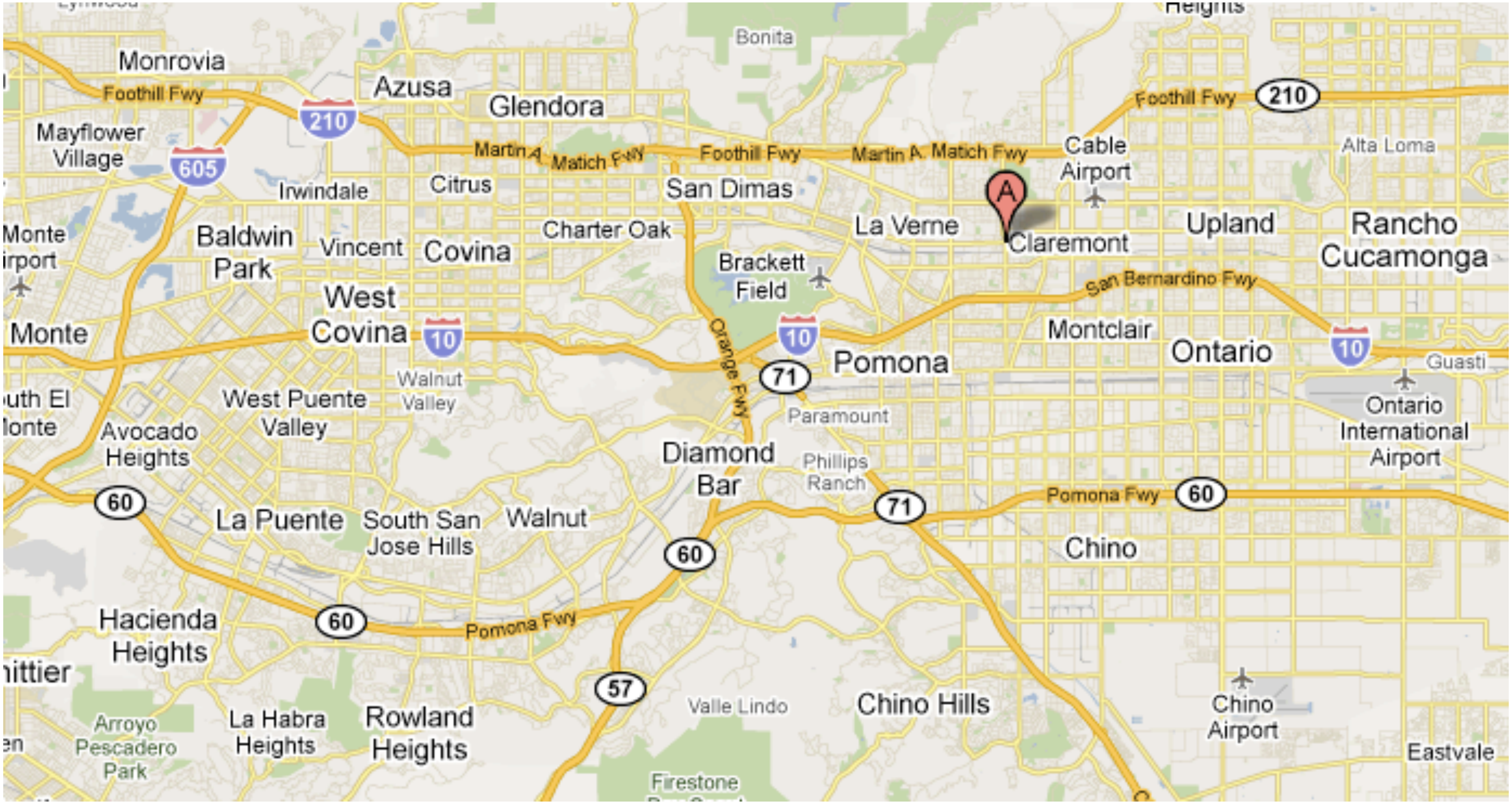
La Puente
South San Jose Hills
Walnut
Pomona Fwy
Chino
Orange Fwy
Hacienda Heights
57
Valle Lindo
Chino Hills
Chino Airport
La Habra Heights
Rowland Heights
Arroyo Pescadero Park
Firestone
Eastvale

Ideas?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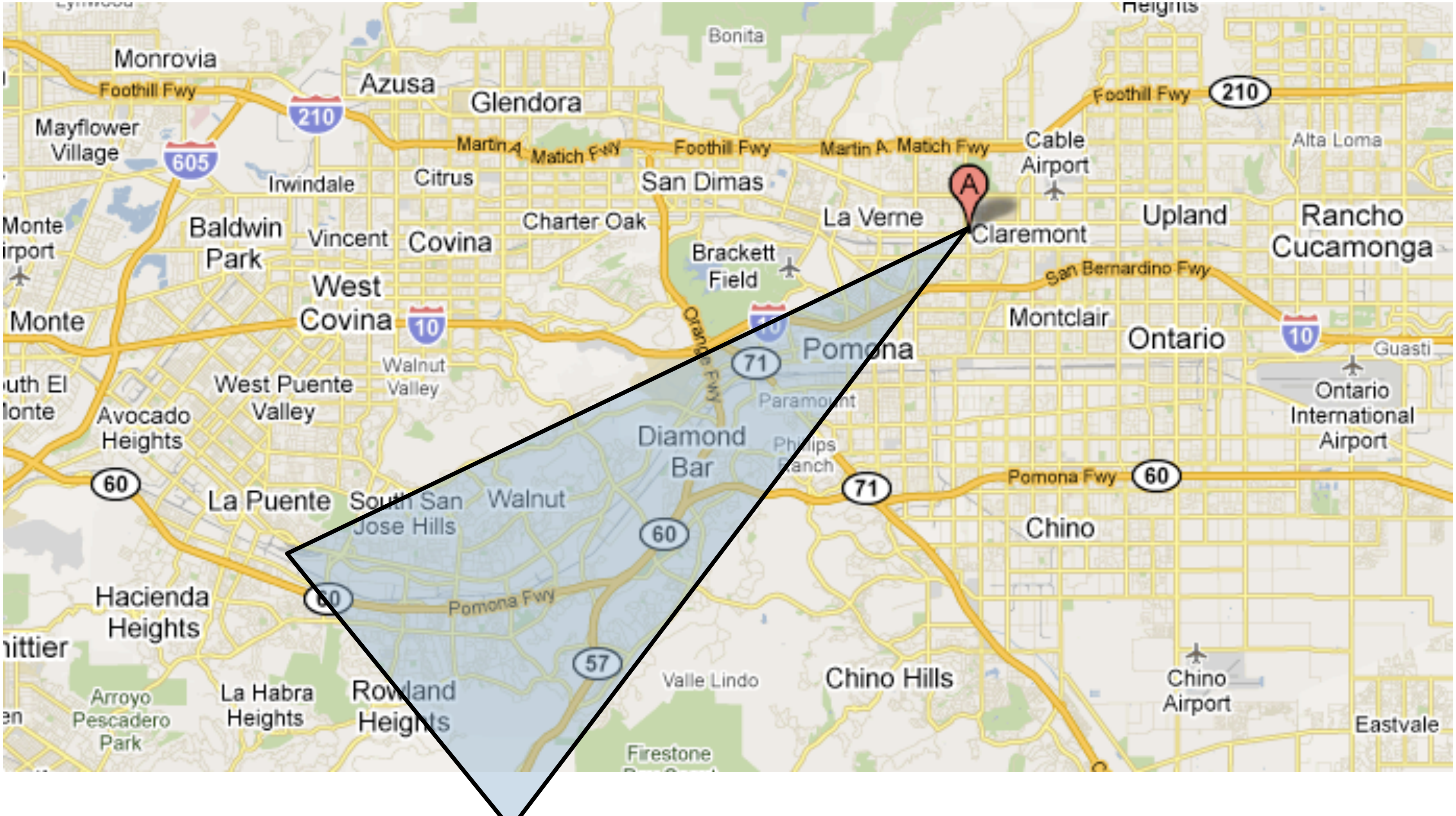
We’d like to bias search towards the actual solution



Informed search

- Order to_visit based on some knowledge of the world that estimates how “good” a state is
    - h(n) is called an evaluation function

- Best-first search
    - rank to_visit based on h(n)
    - take the most desirable state in to_visit first
    - different approaches depending on how we define h(n)

Heuristic

- Merriam-Webster's Online Dictionary
  - Heuristic (pron. \hyu-’ris-tik\): adj. [from Greek heuriskein to discover.] involving or serving as an aid to learning, discovery, or problem-solving by experimental and especially trial-and-error methods

- The Free On-line Dictionary of Computing (2/19/13)
  - heuristic 1. Of or relating to a usually speculative formulation serving as a guide in the investigation or solution of a problem: "The historian discovers the past by the judicious use of such a heuristic device as the 'ideal type'" (Karl J. Weintraub).

INFORMED SEARCH

Heuristic function: h(n)

- An estimate of how close the node is to a goal
- Uses domain-specific knowledge!
- Examples
  - Map path finding?
    - straight-line distance from the node to the goal (“as the crow flies”)
  - 8-puzzle?
    - how many tiles are out of place
    - sum of the “distances” of the out of place tiles
  - Foxes and Chickens?
    - number of passengers on the starting bank

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Resources

- `chickens.py`

Homework

- Assignment 9 (cont'd)