CMU Snake Robot

http://www-cgi.cs.cmu.edu/afs/cs.cmu.edu/Web/People/biorobotics/projects/modsnake/index.html

Informed Search

CS311
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Spring 2013

Some material borrowed from :
Sara Owsley Sood and others

Administrative

- Assignment 1 was due before class
  - how'd it go?
  - come talk to me earlier than later!
- Written problems?
- Assignment 2
  - Mancala (game playing)
  - will be out later today or tomorrow
  - < 2 weeks to complete
  - Can work with a partner
  - tournament!
- Lectures slides posted on the course web page

Uninformed search strategies

Uninformed search strategies use only the information available in the problem definition

- Breadth-first search
- Uniform-cost search
- Depth-first search
- Depth-limited search
- Iterative deepening search

Summary of algorithms

Criterion	Breadth-First	Uniform-Cost	Depth-First	Depth-Limited	Iterative Deepening
Complete?	Yes	Yes	No	No	Yes
Time	$O(b^{d+1})$	$O(b^{\lceil C^*/\epsilon \rceil})$	$O(b^m)$	$O(b^l)$	$O(b^d)$
Space	$O(b^{d+1})$	$O(b^{\lceil C^*/\epsilon \rceil})$	$O(bm)$	$O(bl)$	$O(bd)$
Optimal?	Yes	Yes	No	No	Yes

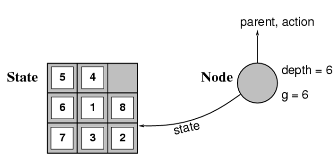
A few subtleties…

What is the difference between a state and a node?

Be Careful! states vs. nodes

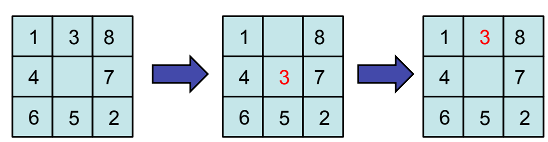
A state is a (representation of) a physical configuration

A node is a data structure constituting part of a search tree includes state, parent node, action, path cost *g(x)*, depth



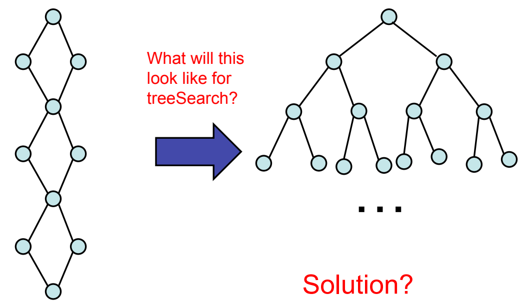
Repeated states

What is the impact of repeated states?




```
def treeSearch(start):
  add start to the frontier
  while frontier isn't empty:
    get the next node from the frontier
      if node contains goal state:
          return solution
      else:
          expand node and add resulting nodes to frontier
```

Can make problems seem harder



Graph search

Keep track of nodes that have been visited (explored)

Only add nodes to the frontier if their *state* has not been seen before

```
def graphSearch(start):
  add start to the frontier
  set explored to empty
  while frontier isn't empty:
    get the next node from the frontier
      if node contains goal state:
            return solution
      else:
            add node to explored set
            expand node and add resulting nodes to frontier,
              if they are not in frontier or explored
```

Graph search implications?

We're keeping track of all of the states that we've previously seen

For problems with lots of repeated states, this is a huge time savings

The tradeoff is that we blow-up the memory usage
- Space graphDFS?
  - $O(b^m)$

Something to think about, but in practice, we often just use the tree approach

8-puzzle revisited

The average depth of a solution for an 8-puzzle is 22 moves

What do you think the average branching factor is?
- ~3 (center square has 4 options, corners have 2 and edges have 3)

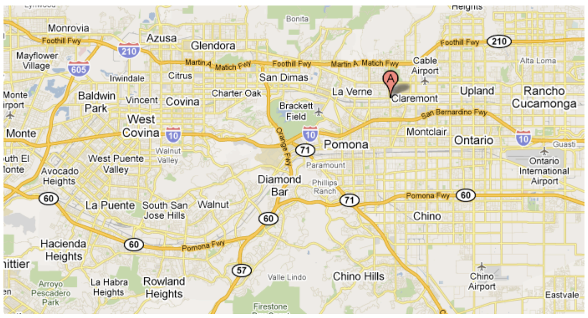
An exhaustive search would require $\sim 3^{22} = 3.1 \times 10^{10}$ states
- BFS: 10 terabytes of memory
- DFS: 8 hours (assuming one million nodes/second)
- IDS: ~9 hours

Can we do better?

1	3	8
4		7
6	5	2

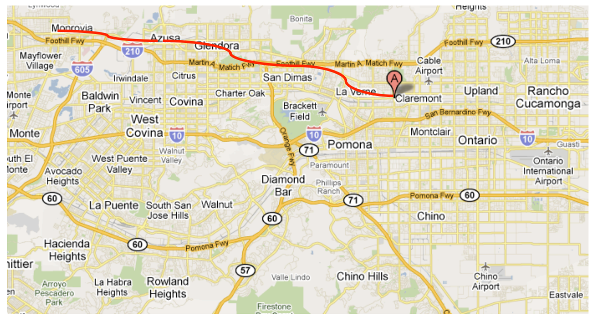
from: Claremont to:Rowland Heights

What would the search algorithms do?



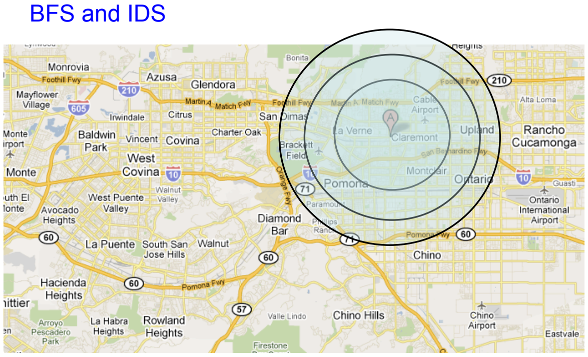
from: Claremont to:Rowland Heights

DFS



from: Claremont to:Rowland Heights

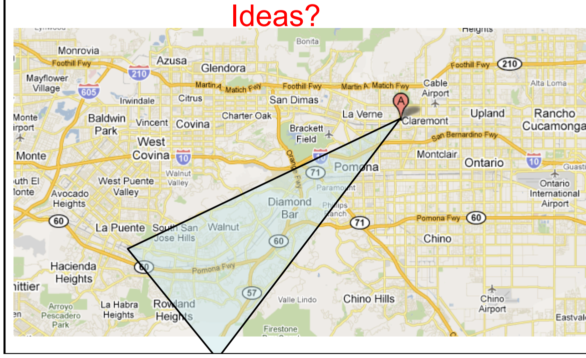
BFS and IDS



from: Claremont to:Rowland Heights

We'd like to bias search towards the actual solution

Ideas?



Informed search

Order the *frontier* based on some knowledge of the world that estimates how "good" a state is

- *f(n)* is called an evaluation function

Best-first search

- rank the frontier based on *f(n)*
- take the most desirable state in the frontier first
- different approaches depending on how we define *f(n)*

```
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  add start to the frontier
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      else:
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```

Heuristic

Merriam-Webster's Online Dictionary

Heuristic (pron. \hyu-ˈris-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).

Heuristic function: *h(n)*

An estimate of how close the node is to a goal

Uses domain-specific knowledge

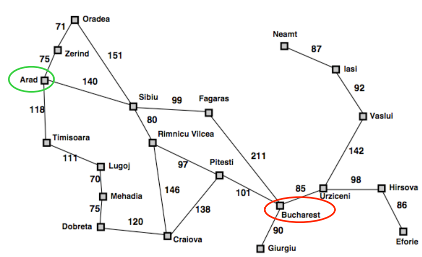
Examples

- 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
- Missionaries and cannibals?
  - number of people on the starting bank

Greedy best-first search

f(n) = h(n)

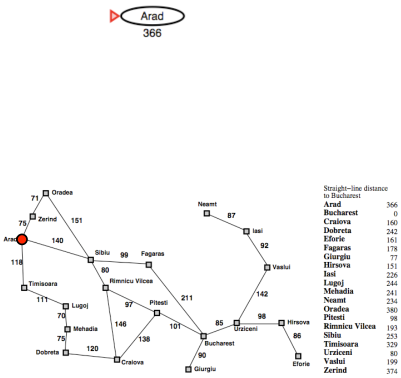
rank nodes by how close we think they are to the goal



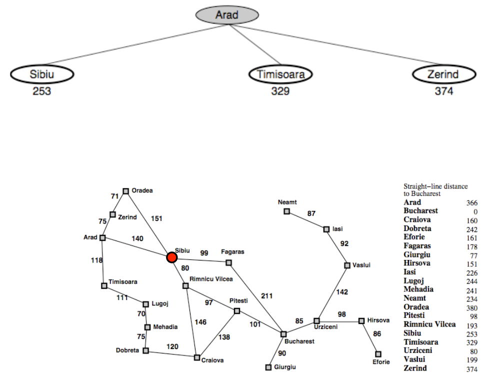
Straight−line distance to Bucharest	
Arad	366
Bucharest	0
Craiova	160
Dobreta	242
Eforie	161
Fagaras	178
Giurgiu	77
Hirsova	151
Iasi	226
Lugoj	244
Mehadia	241
Neamt	234
Oradea	380
Pitesti	98
Rimnicu Vilcea	193
Sibiu	253
Timisoara	329
Urziceni	80
Vaslui	199
Zerind	374

Arad to Bucharest

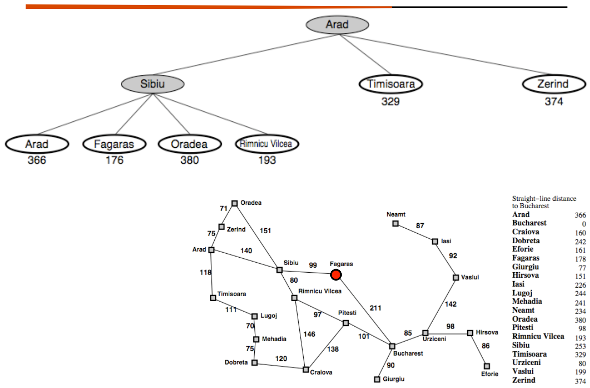
Greedy best-first search



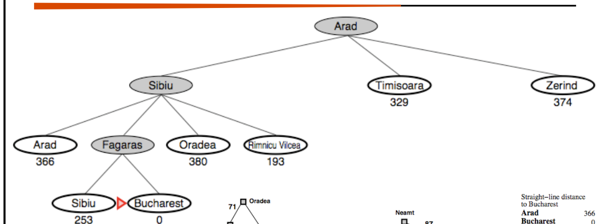
Greedy best-first search



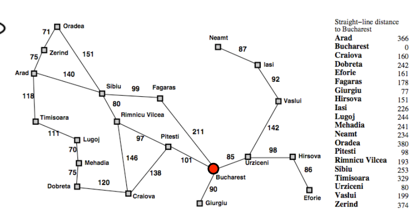
Greedy best-first search



Greedy best-first search



Is this right/
optimal?



Problems with greedy best-first search

Time?

– $O(b^m)$ – but can be much faster

Space?

– $O(b^m)$ – have to keep them in memory to rank

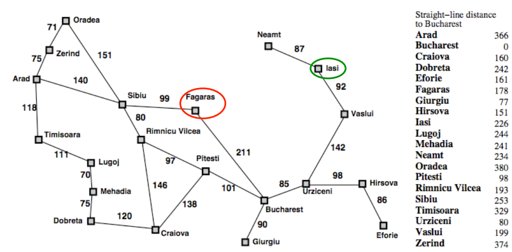
Complete?

Problems with greedy best-first search

Complete?

– Graph search, yes

– Tree search, no

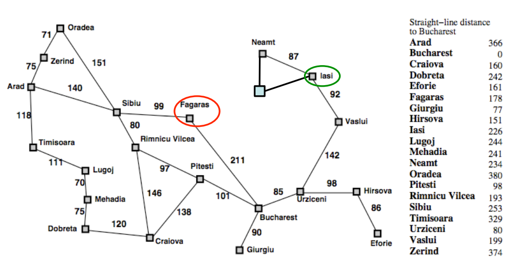


Problems with greedy best-first search

Complete?

– Graph search, yes

– Tree search, no



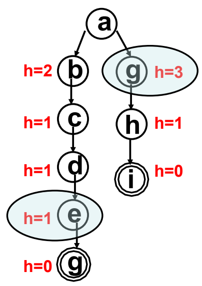
Problems with greedy best-first search

Optimal?

Problems with greedy best-first search

Optimal?

– no, as we just saw in the map example



Sometimes it's too greedy

Shortest path from a to g?

What is the problem?

A* search

Idea:

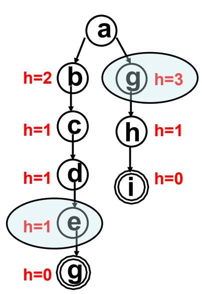
- don't expand paths that are already expensive
- take into account the path cost!

$f(n) = g(n) + h(n)$

- $g(n)$ is the path cost so far
- $h(n)$ is our estimate of the cost to the goal

$f(n)$ is our estimate of the total path cost to the goal through n

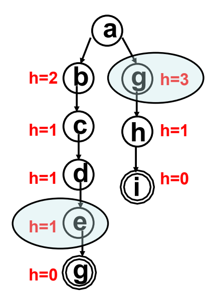
A* search



f(n) = ?

f(n) = ?

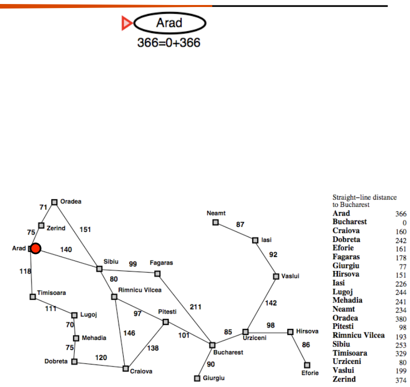
A* search



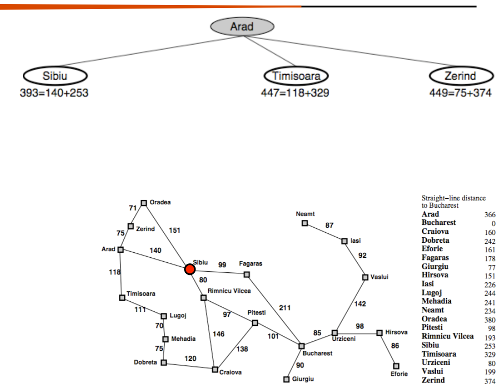
f(n) = 4

f(n) = 5

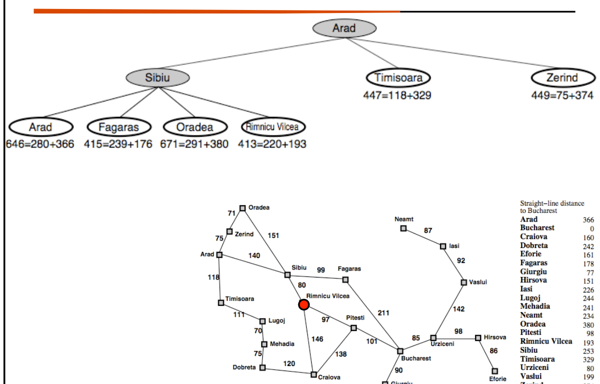
A* search



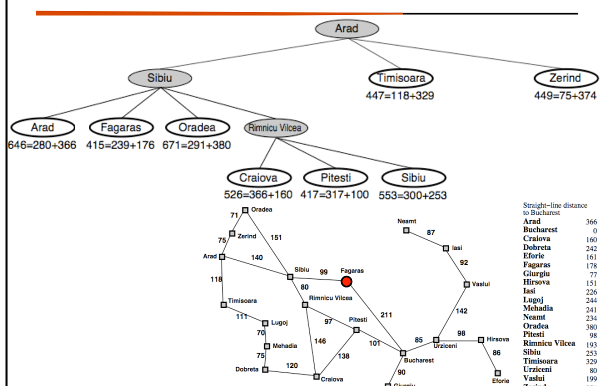
A* search



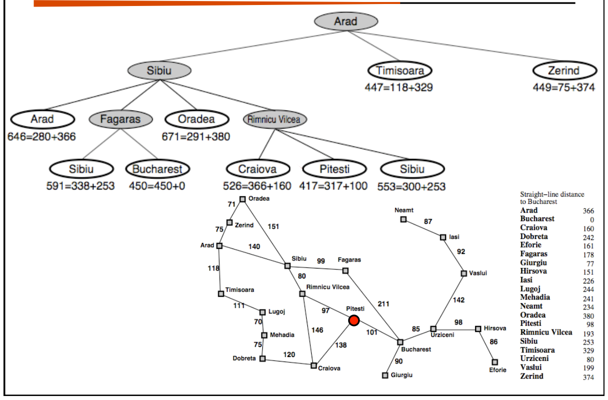
A* search



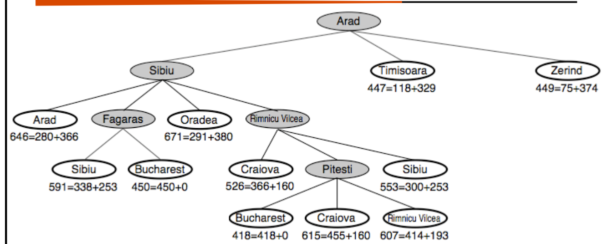
A* search



A* search



A* search



Admissible heuristics

A heuristic function is ***admissible*** if it never overestimates
- if h*(n) is the actual distance to the goal
- h(n) ≤ h*(n)

An admissible heuristic is optimistic (it always thinks the goal is closer than it actually is)

Is the straight-line distance admissible?

the PRICE is Right

closest to the actual "price"
without going over

A* properties

Time?
- depends on heuristic, but generally exponential

Space?
- exponential (have to keep all the nodes in memory/frontier)

Complete?
- **YES**

Optimal?
- **YES**, if the heuristic is admissible
- Why?
  - If we could overestimate, then we could find (that is remove from the queue) a goal node that was suboptimal because our estimate for the optimal goal was too large

A point of technicality

Technically if the heuristic isn't admissible, then the search algorithm that uses f(n) = g(n) + h(n) is call "Algorithm A"

A* algorithm requires that the heuristic is admissible

That said, you'll often hear the later referred to as A*

Algorithm A is not optimal

Admissible heuristics

8-puzzle

1	3	8
4		7
6	5	2

1	2	5
4		8
3	6	7

	1	2
3	4	5
6	7	8

goal

Admissible heuristics

8-puzzle

- $h_1(n)$ = number of misplaced tiles?
- $h_2(n)$ = manhattan distance?

admissible?

$h_1 = 7$
$h_2 = 12$

1	3	8
4		7
6	5	2

$h_1 = 8$
$h_2 = 8$

1	2	5
4		8
3	6	7

	1	2
3	4	5
6	7	8

goal

Admissible heuristics

8-puzzle

- $h_1(n)$ = number of misplaced tiles?
- $h_2(n)$ = manhattan distance?

which is better?

$h_1 = 7$
$h_2 = 12$

1	3	8
4		7
6	5	2

$h_1 = 8$
$h_2 = 8$

1	2	5
4		8
3	6	7

	1	2
3	4	5
6	7	8

goal

Dominance

Given two admissible heuristic functions

- if $h_i(n) \geq h_j(n)$ for all n
- then $h_i(n)$ *dominates* $h_j(n)$

A dominant function is always better. Why?

- It always give a better (i.e. closer) estimate to the actual path cost, without going over

What about?

- $h_1(n)$ = number of misplaced tiles
- $h_2(n)$ = manhattan distance

Dominance

$h_2(n)$ dominates $h_1(n)$

depth of solution	IDS	A*(h1)	A*(h2)
2	10	6	6
4	112	13	12
6	680	20	18
8	6384	39	25
10	47127	93	39
12	3644035	227	73
14		539	113
16		1301	211
18		3056	363
20		7276	676

average nodes expanded for 8-puzzle problems

Combining heuristics

Sometimes, we have multiple admissible heuristics, but none dominates

What then?

- We can take the max of all the heuristics!

Why?

- Since they're all admissible, we know none overestimate
- taking the max gives us a closer/better estimate
- overall, a better heuristic function

Relaxed problems

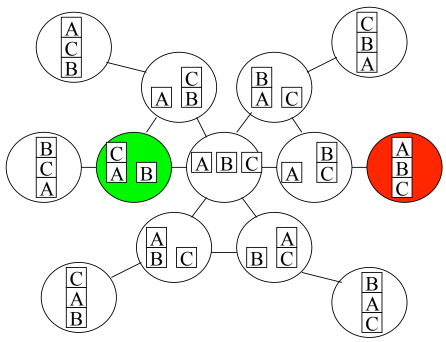
A problem with fewer restrictions on the actions is called a relaxed problem

The cost of an optimal solution to a relaxed problem is an admissible heuristic for the original problem

8-puzzle: relaxed problems?
If the rules of the 8-puzzle are relaxed so that a tile can move anywhere, then $h_1(n)$ gives the shortest solution

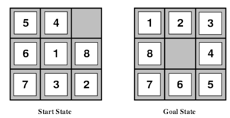
If the rules are relaxed so that a tile can move to *any adjacent square,* then $h_2(n)$ gives the shortest solution

Using A* in Planning

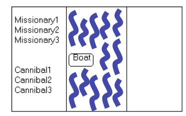


Creating Heuristics

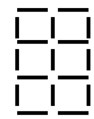
8-Puzzle



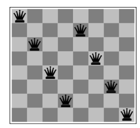
Missionaries and Cannibals



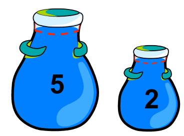
Remove 5 Sticks



N-Queens



Water Jug Problem



Route Planning