

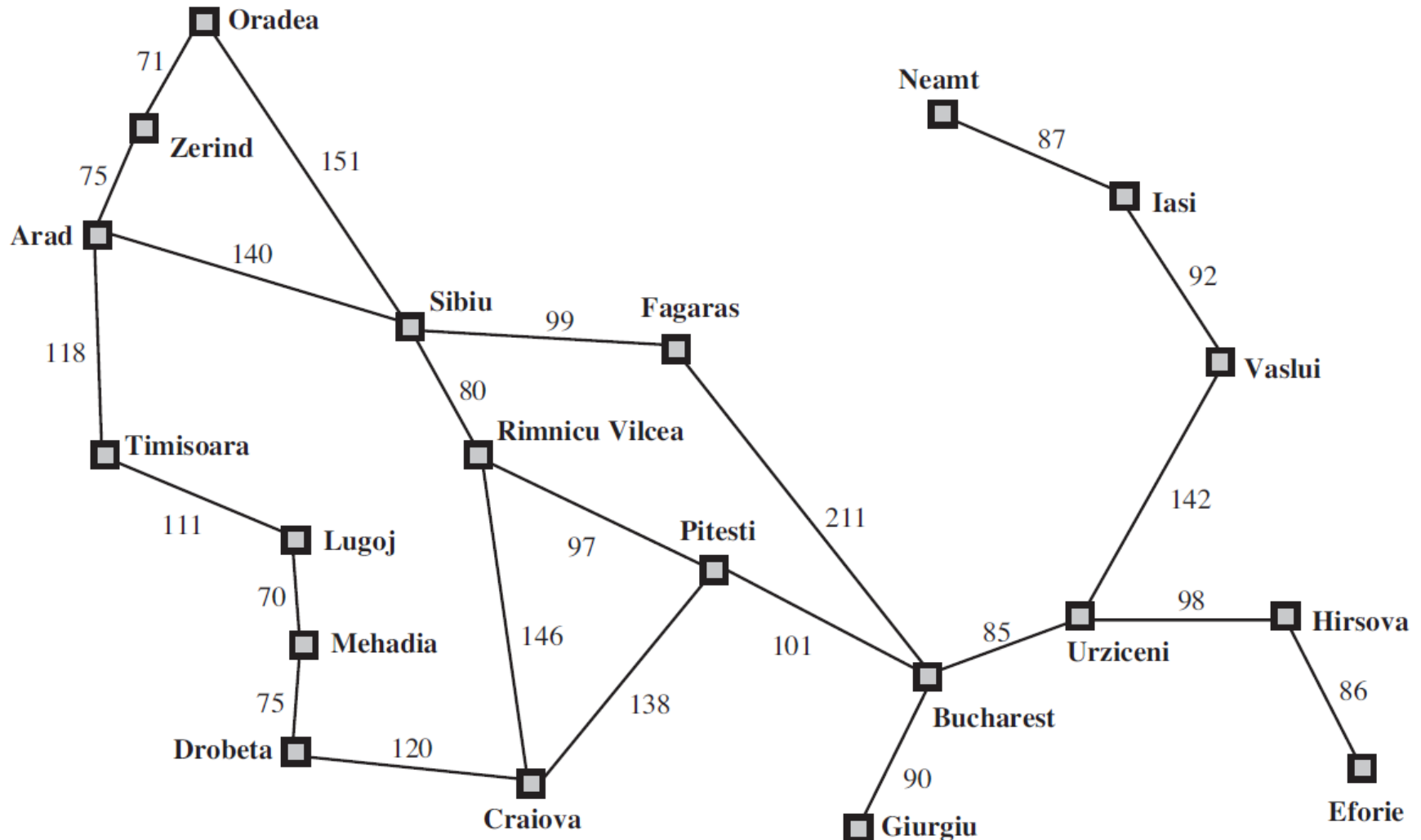
# Informed Search

CS161

Prof. Guy Van den Broeck

# Best-First Search Motivation

Evaluation function  $f(n)$ ?

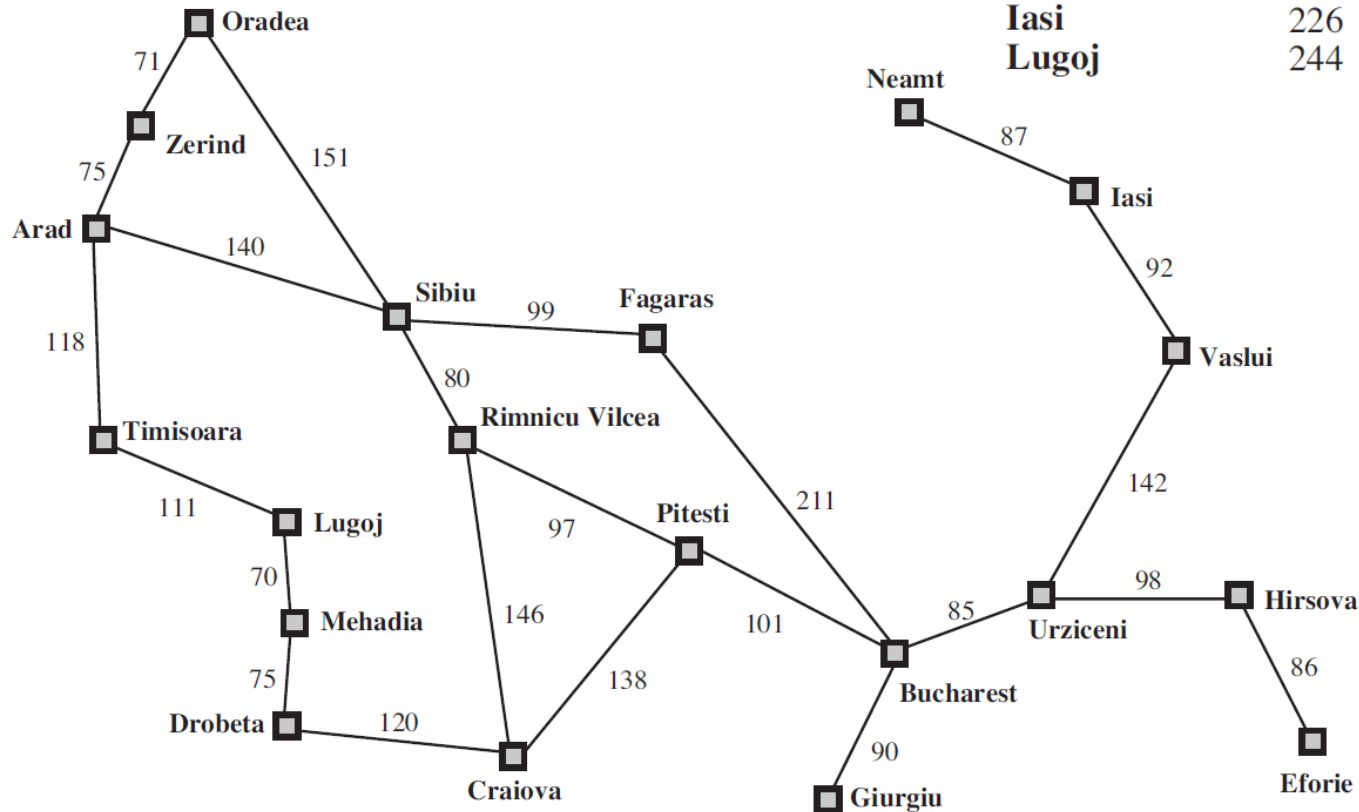


# Heuristic Search Motivation

Heuristic function  $h(n)=$

Arad	366
Bucharest	0
Craiova	160
Drobeta	242
Eforie	161
Fagaras	176
Giurgiu	77
Hirsova	151
Iasi	226
Lugoj	244

Mehadia	241
Neamt	234
Oradea	380
Pitesti	100
Rimnicu Vilcea	193
Sibiu	253
Timisoara	329
Urziceni	80
Vaslui	199
Zerind	374



# Greedy Best-First Search

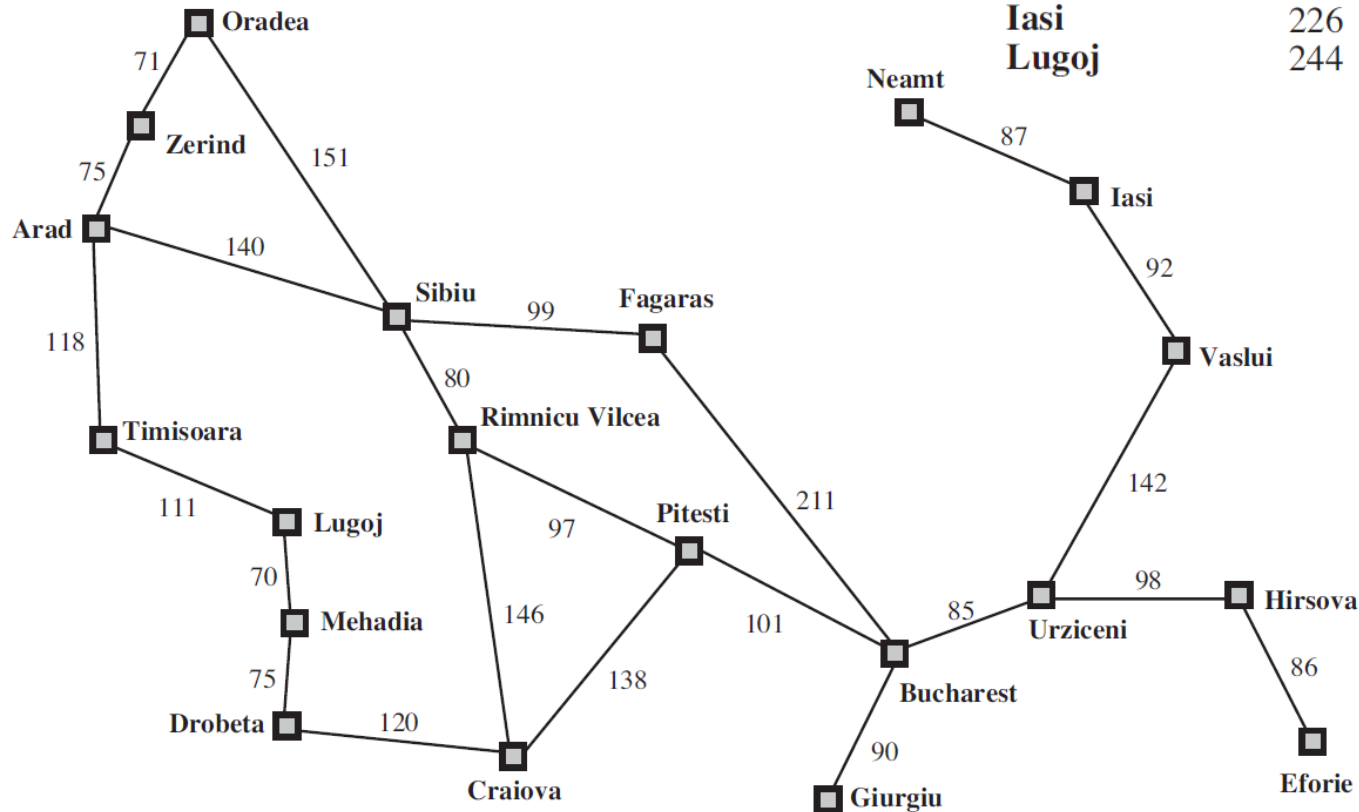
- Minimize estimated cost to goal
    - $h(n)$  estimated cost of cheapest path from  $n$  to goal
  - Evaluation function to choose node  $f(n) = h(n)$
  - Require:  $h(n) = 0$  when  $n$  is goal
  - Where does  $h$  come from?
    - Not easily read from search problem formulation
    - Application-specific
- E.g., straight-line distance from map coordinates

# Arad to Bucharest?

Heuristic function  $h(n)=$

Arad	366
Bucharest	0
Craiova	160
Drobeta	242
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# Properties

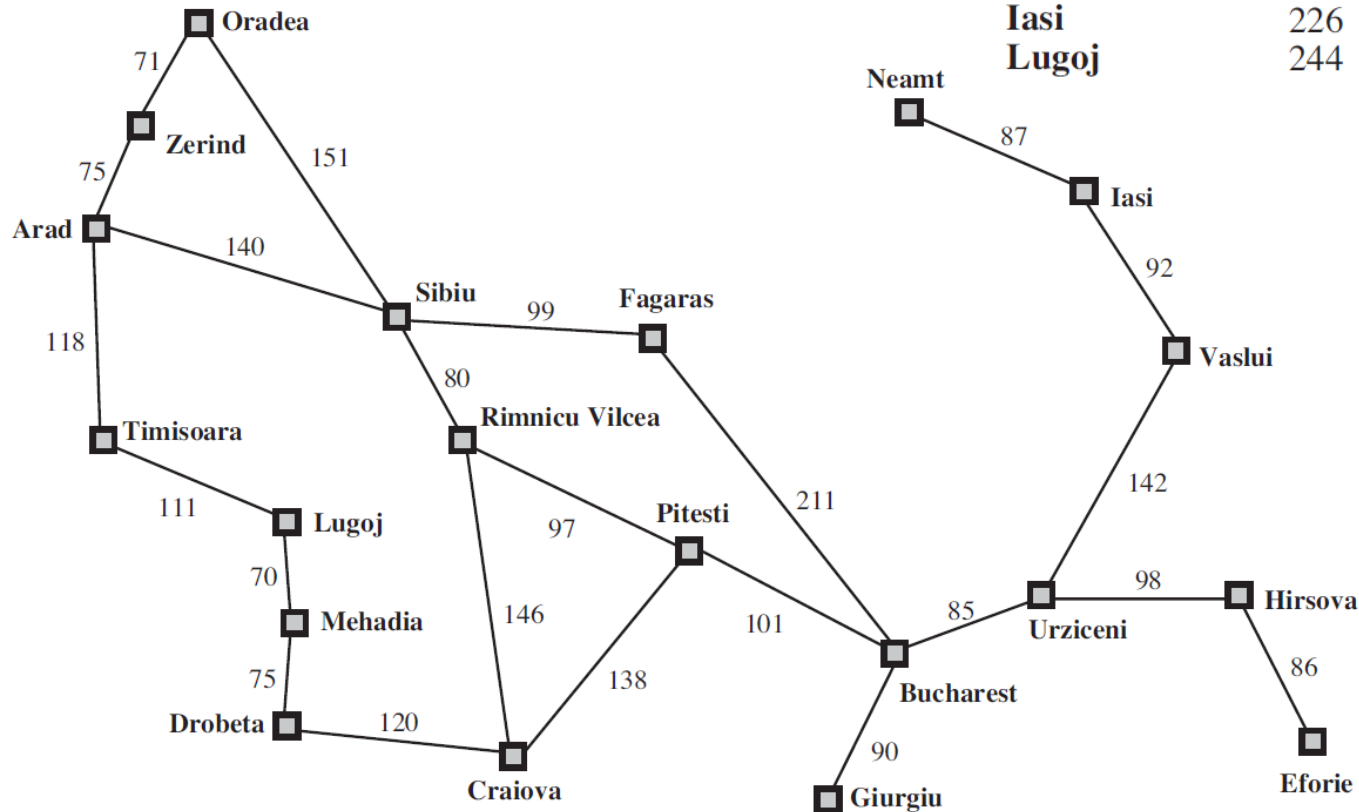
- Arad to Bucharest 32km longer than optimal
- Minimal search cost:  
Solution was found with no unnecessary expansion!
- Optimal? No
- Complete?

# Iasi to Fagaras?

Heuristic function  $h(n)=$

Arad	366
Bucharest	0
Craiova	160
Drobeta	242
Eforie	161
Fagaras	176
Giurgiu	77
Hirsova	151
Iasi	226
Lugoj	244

Mehadia	241
Neamt	234
Oradea	380
Pitesti	100
Rimnicu Vilcea	193
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Vaslui	199
Zerind	374



# Properties

- Arad to Bucharest 32km longer than optimal
- Minimal search cost:  
Solution was found with no unnecessary expansion!
- Optimal? No
- Complete? No
  - Infinite paths
  - Yes if finite state space with graph search
- Time and Space Complexity?  
 $O(b^m)$  -- when  $h(n) = 0$  it's blind search!



# How to fix this mess?

- Greedy best-first search with heuristic  $h(n)$  is too greedy  
no idea where it came from...
- Uniform-cost search with cost  $g(n)$  is too conservative  
no idea where the goal is...

Solution?

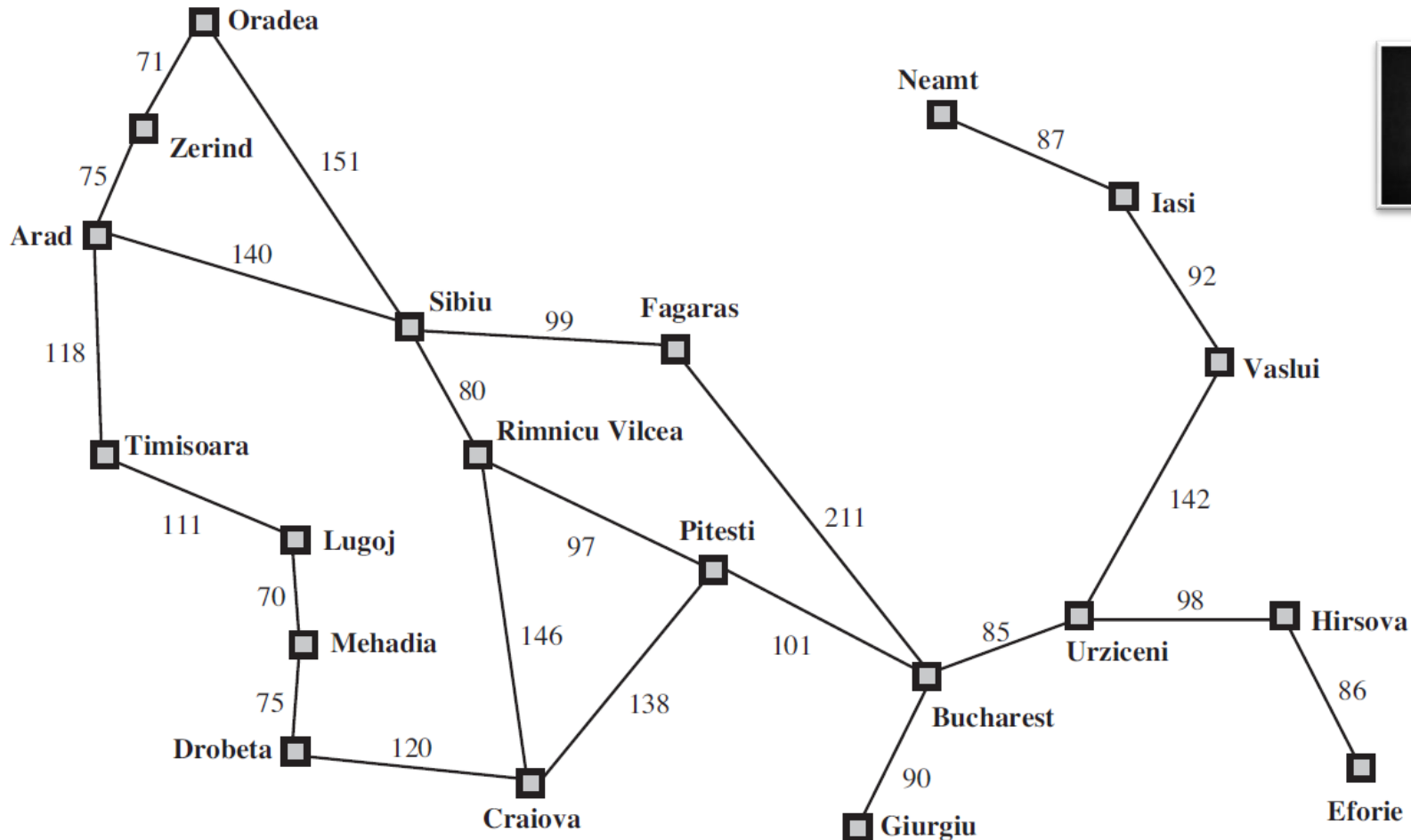
# A\* Search

- $f(n) = g(n) + h(n)$ 
  - $g(n)$  = distance from start
  - $h(n)$  = heuristic
- Estimated cost of cheapest solution **through n**



# A\* Search

Arad	366	Mehadia	241
Bucharest	0	Neamt	234
Craiova	160	Oradea	380
Drobeta	242	Pitesti	100
Eforie	161	Rimnicu Vilcea	193
Fagaras	176	Sibiu	253
Giurgiu	77	Timisoara	329
Hirsova	151	Urziceni	80
Iasi	226	Vaslui	199
Lugoj	244	Zerind	374



# Heuristic Properties



# Optimality of $A^*$



# Memory-Bounded Heuristic Search



# Constructing Heuristics



# Effective Branching Factor

	Search Cost (nodes generated)			Effective Branching Factor		
$d$	IDS	$A^*(h_1)$	$A^*(h_2)$	IDS	$A^*(h_1)$	$A^*(h_2)$
2	10	6	6	2.45	1.79	1.79
4	112	13	12	2.87	1.48	1.45
6	680	20	18	2.73	1.34	1.30
8	6384	39	25	2.80	1.33	1.24
10	47127	93	39	2.79	1.38	1.22
12	3644035	227	73	2.78	1.42	1.24
14	—	539	113	—	1.44	1.23
16	—	1301	211	—	1.45	1.25
18	—	3056	363	—	1.46	1.26
20	—	7276	676	—	1.47	1.27
22	—	18094	1219	—	1.48	1.28
24	—	39135	1641	—	1.48	1.26

**Figure 3.29** Comparison of the search costs and effective branching factors for the ITERATIVE-DEEPENING-SEARCH and  $A^*$  algorithms with  $h_1$ ,  $h_2$ . Data are averaged over 100 instances of the 8-puzzle for each of various solution lengths  $d$ .



# Relaxed Problems



# Subproblems



# Korf's Breakthroughs

- 15-puzzle optimal (1985)
- 24-puzzle optimal (1996)
- Rubik's cube optimal (1997)
- 15-puzzle exhaustive (2005)
- ...