Uninformed Search (contd)

Chapter 3

(Based on slides by Stuart Russell, Subbarao Kambhampati, Dan Weld, Oren Etzioni, Henry Kautz, and other UW-AI faculty)

Atomic Agent

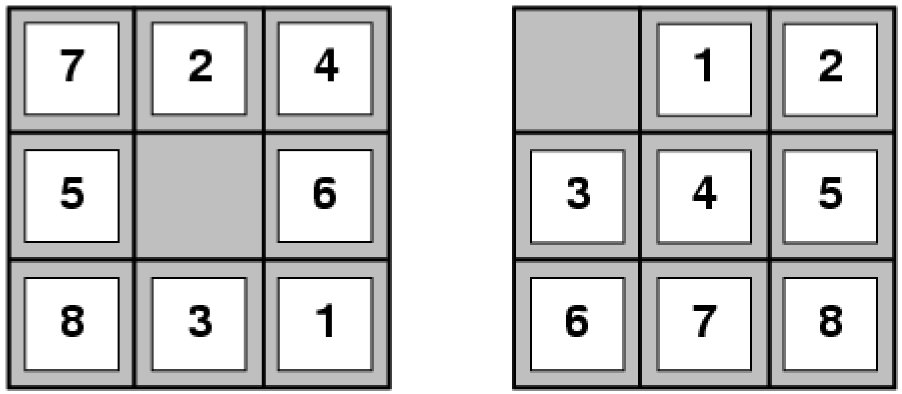
Input:

- Set of states
- Operators [and costs]
- Start state
- Goal state [test]

Output:

- Path: start $\Rightarrow$ a state satisfying goal test
- [May require shortest path]

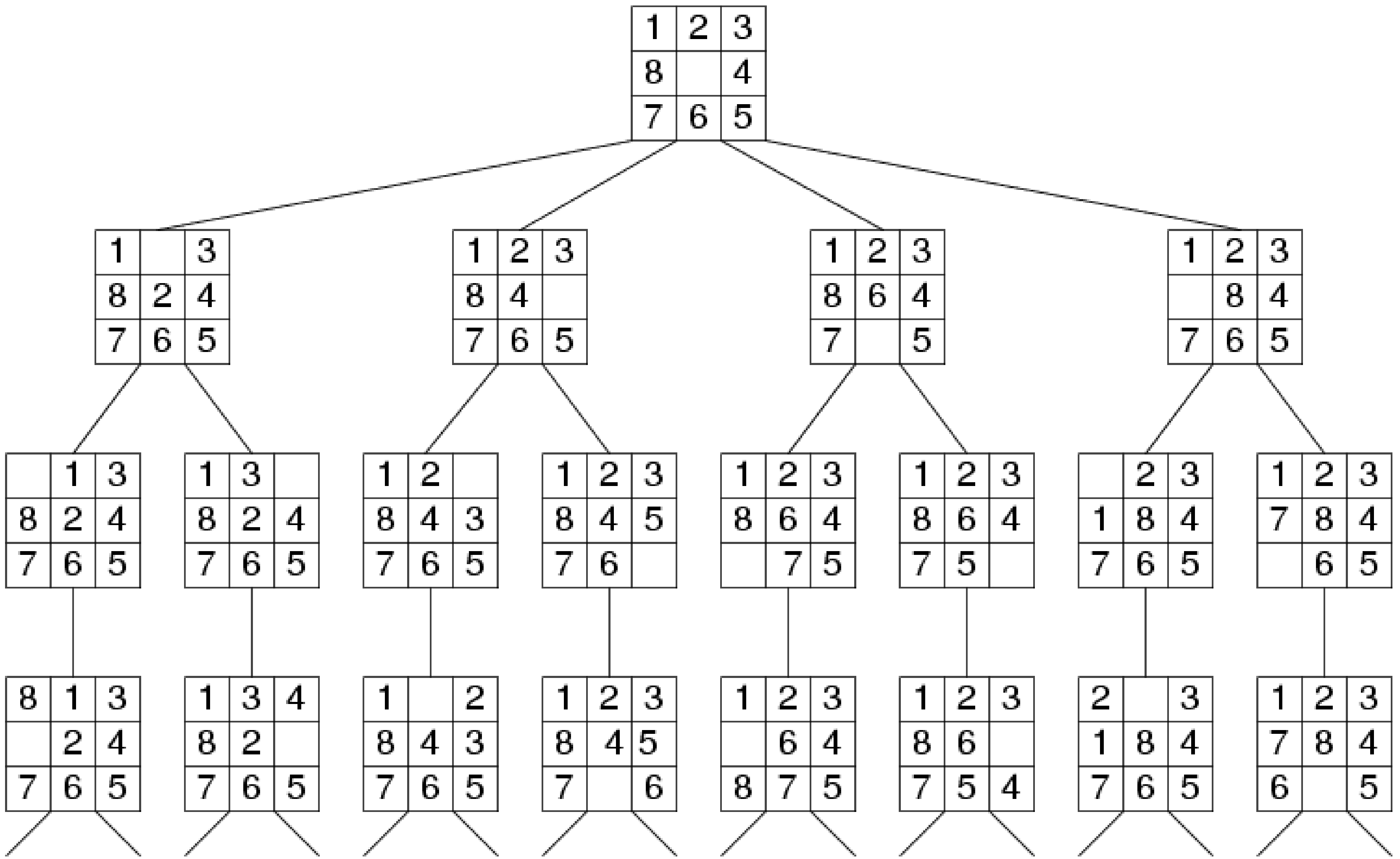
Example: The 8-puzzle



Start State Goal State

- states?
- actions?
- goal test?
- path cost?

Search Tree Example:
Fragment of 8-Puzzle Problem Space



Search strategies

- A search strategy is defined by picking the order of node expansion
- Strategies are evaluated along the following dimensions:
  - completeness: does it always find a solution if one exists?
  - time complexity: number of nodes generated
  - space complexity: maximum number of nodes in memory
  - optimality: does it always find a least-cost solution?
  - systematicity: does it visit each state at most once?

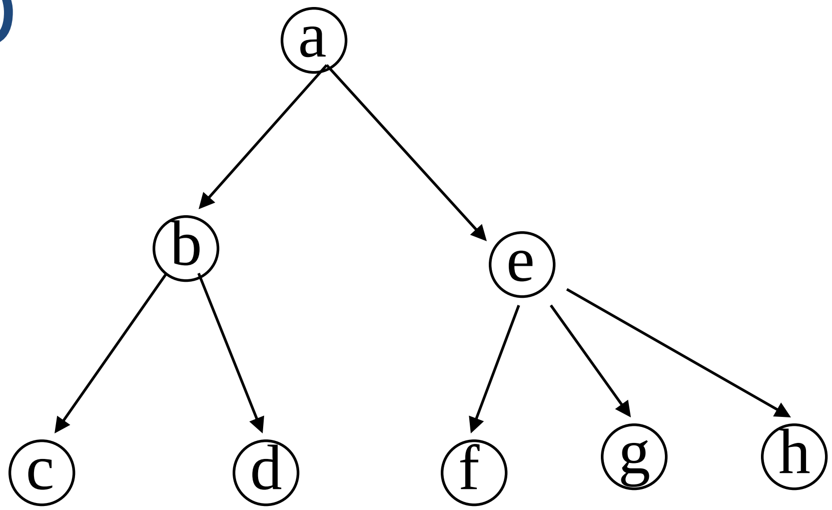
- Time and space complexity are measured in terms of
  - *b:* maximum branching factor of the search tree
  - *d:* depth of the least-cost solution
  - *m*: maximum depth of the state space (may be ∞)

Uninformed search strategies

- Uninformed search strategies use only the information available in the problem definition
- Breadth-first search
- Depth-first search
- Depth-limited search
- Iterative deepening search

Depth First Search

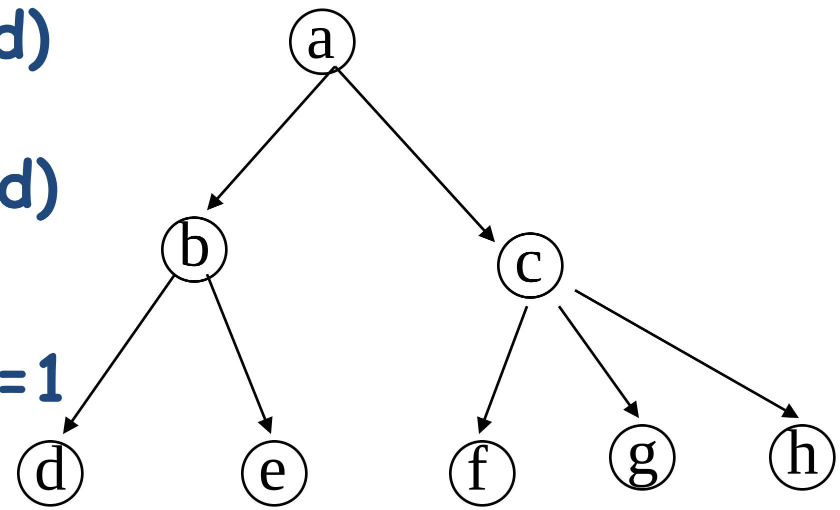
- Maintain stack of nodes to visit
- Evaluation
  - Complete? No
  - Time Complexity? O(b^m)
  - Space Complexity? O(bm)



http://www.youtube.com/watch?v=dtoFAvtVE4U

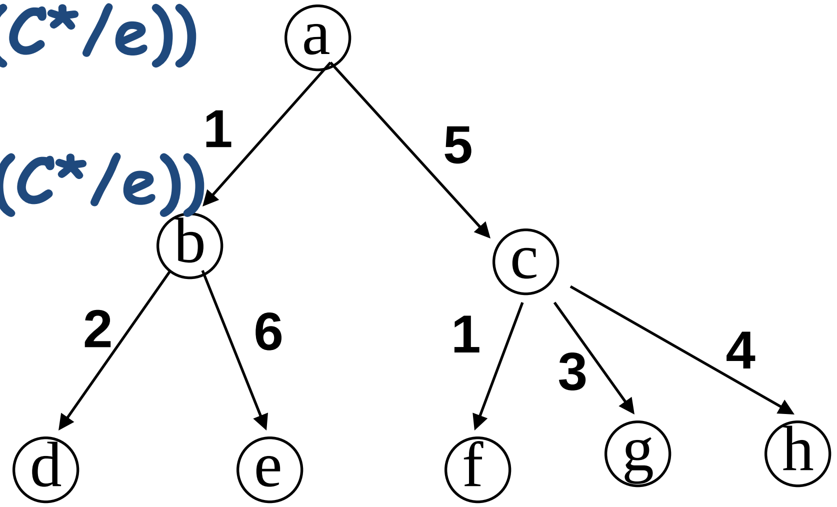
Breadth First Search: shortest first

- Maintain queue of nodes to visit
- Evaluation
  - Complete? Yes (b is finite)
  - Time Complexity? O(b^d)
  - Space Complexity? O(b^d)
  - Optimal? Yes, if stepcost=1



Uniform Cost Search: cheapest first

- Maintain queue of nodes to visit
- Evaluation
  - Complete? Yes (b is finite)
  - Time Complexity? O(b^(C*/e))
  - Space Complexity? O(b^(C*/e))
  - Optimal? Yes



http://www.youtube.com/watch?v=z6lUnb9ktkE

Memory Limitation

- Suppose:

  2 GHz CPU

  1 GB main memory

  100 instructions / expansion

  5 bytes / node

  200,000 expansions / sec

  Memory filled in 100 sec … < 2 minutes

Idea 1: Beam Search

- Maintain a constant sized frontier
- Whenever the frontier becomes large
  - Prune the worst nodes

Optimal: no

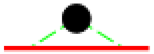
Complete: no

Idea 2: Iterative deepening search

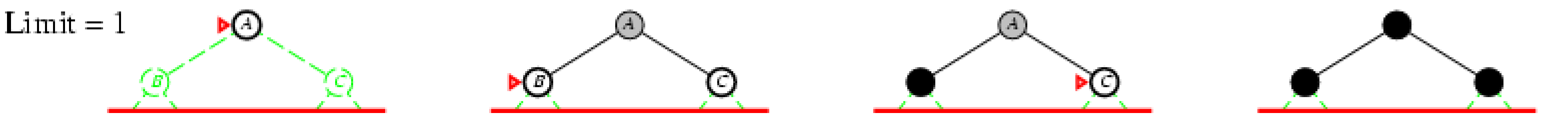
```
function ITERATIVE-DEEPENING-SEARCH( problem) returns a solution, or fail-
ure
    inputs: problem, a problem

    for depth ← 0 to ∞ do
        result ← DEPTH-LIMITED-SEARCH( problem, depth)
        if result ≠ cutoff then return result
```

Iterative deepening search l =0

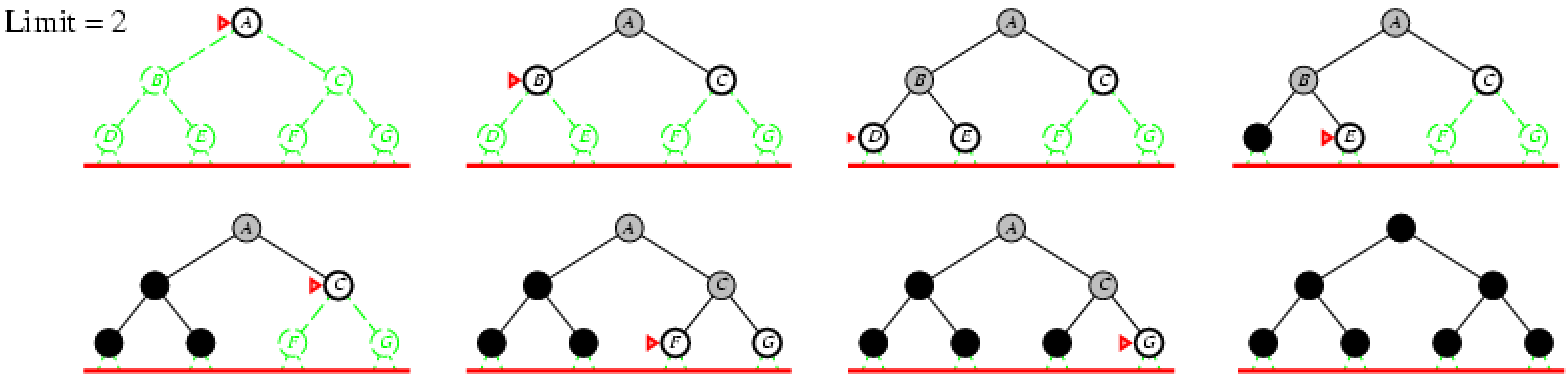
Limit = 0



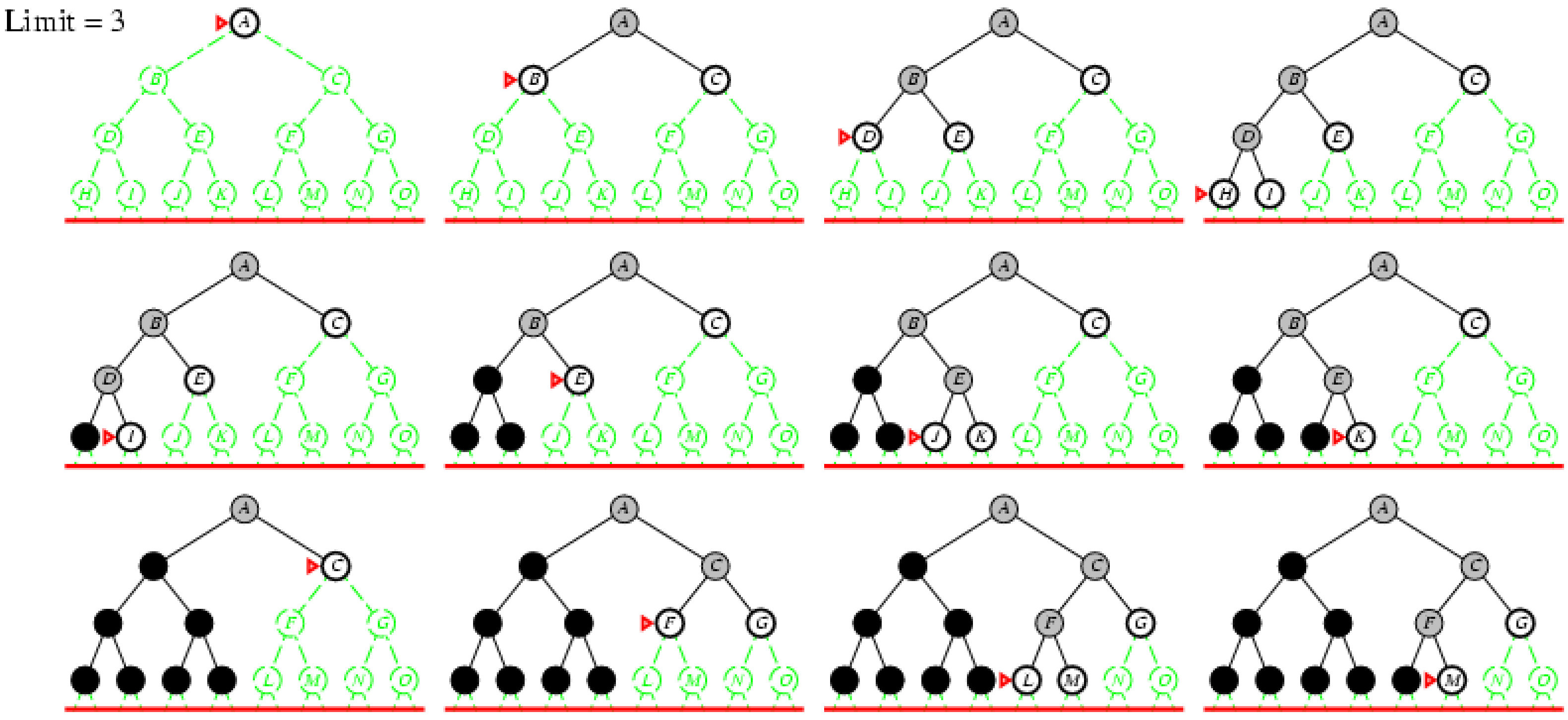
Iterative deepening search *l* =1



Iterative deepening search l =2



Iterative deepening search *l* =3



Iterative deepening search

- Number of nodes generated in a depth-limited search to depth *d* with branching factor *b*:
    - $N_{DLS} = b^0 + b^1 + b^2 + \ldots + b^{d-2} + b^{d-1} + b^d$

- Number of nodes generated in an iterative deepening search to depth *d* with branching factor *b*:
    - $N_{IDS} = (d+1)b^0 + d\ b\text{^}^1 + (d-1)b\text{^}^2 + \ldots + 3b^{d-2} + 2b^{d-1} + 1b^d$

- Asymptotic ratio: (b+1)/(b-1)

- For *b = 10*, *d = 5*,
-
    - N_{DLS} = 1 + 10 + 100 + 1,000 + 10,000 + 100,000 = 111,111
    -
    - N_{IDS} = 6 + 50 + 400 + 3,000 + 20,000 + 100,000 = 123,456
    -

- Overhead = (123,456 - 111,111)/111,111 = 11%

Iterative deepening search

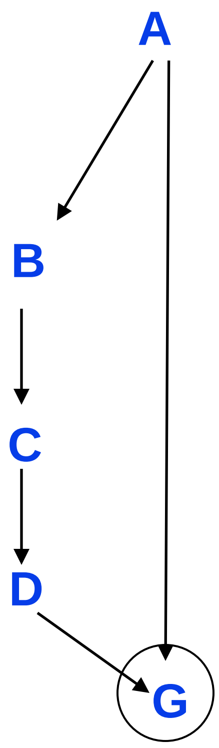
- Complete?
  - Yes
- Time?
  - $(d+1)b^0 + d\, b^1 + (d-1)b^2 + \ldots + b^d = O(b^{d+1})$
- Space?
  - $O(bd)$
- Optimal?
  - Yes, if step cost = 1
  - Can be modified to explore uniform cost tree (iterative lengthening)
- Systematic?

Cost of Iterative Deepening

b	ratio ID to DFS
2	3
3	2
5	1.5
10	1.2
25	1.08
100	1.02

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

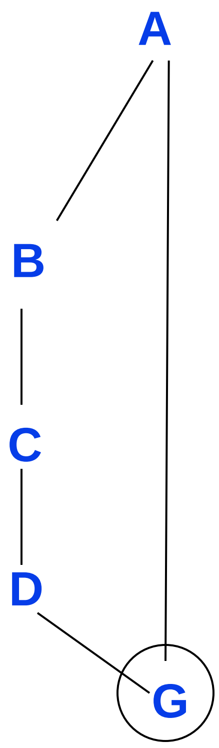


BFS: A,B,G

DFS: A,B,C,D,G

IDDFS: (A), (A, B, G)

Note that IDDFS can do fewer expansions than DFS on a graph shaped search space.



BFS: A,B,G

DFS: A,B,A,B,A,B,A,B,A,B

IDDFS: (A), (A, B, G)

Note that IDDFS can do fewer expansions than DFS on a graph shaped search space.

Search on undirected graphs or directed graphs with cycles…

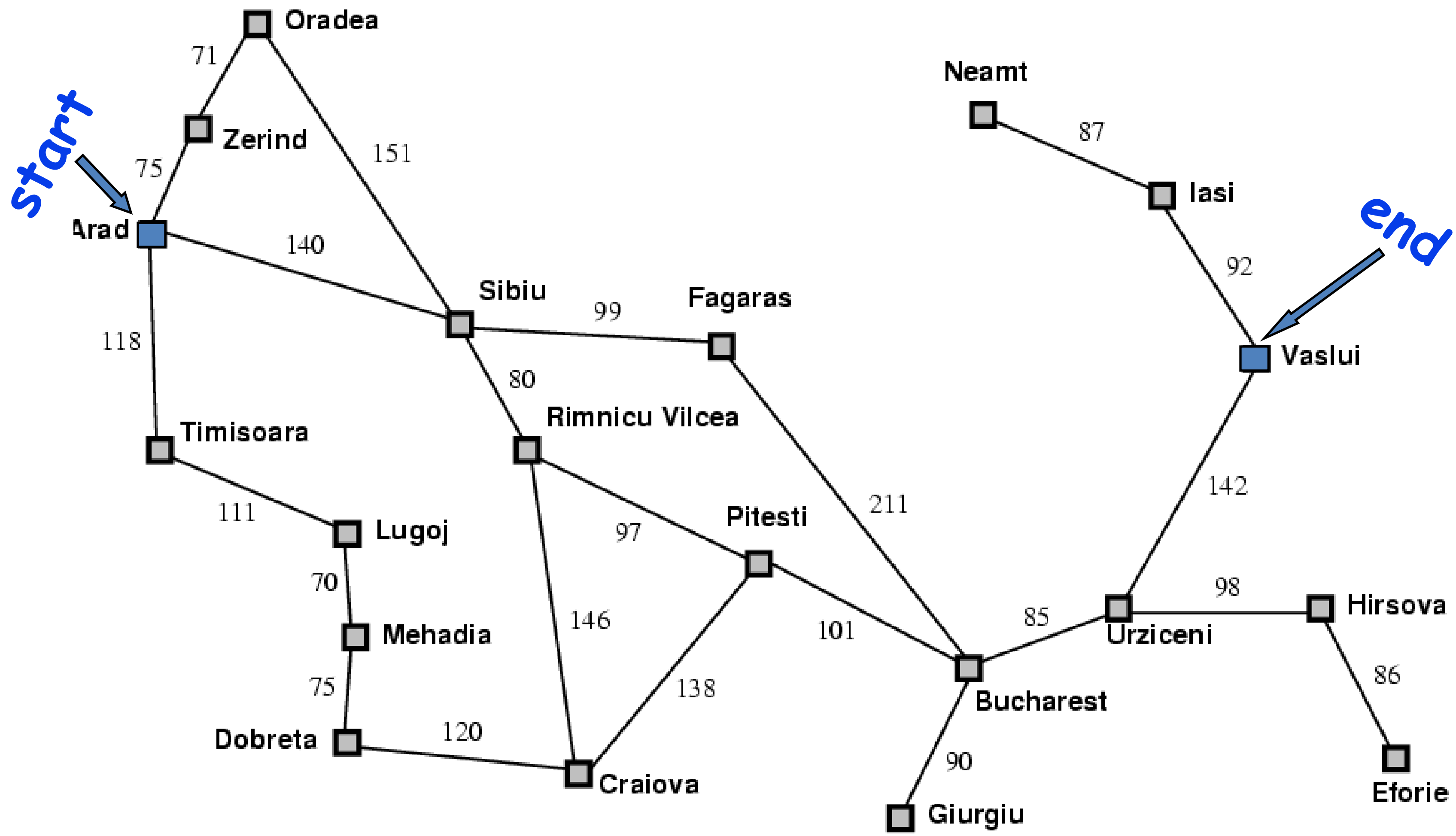
Cycles galore…

Graph (instead of tree) Search: Handling repeated nodes

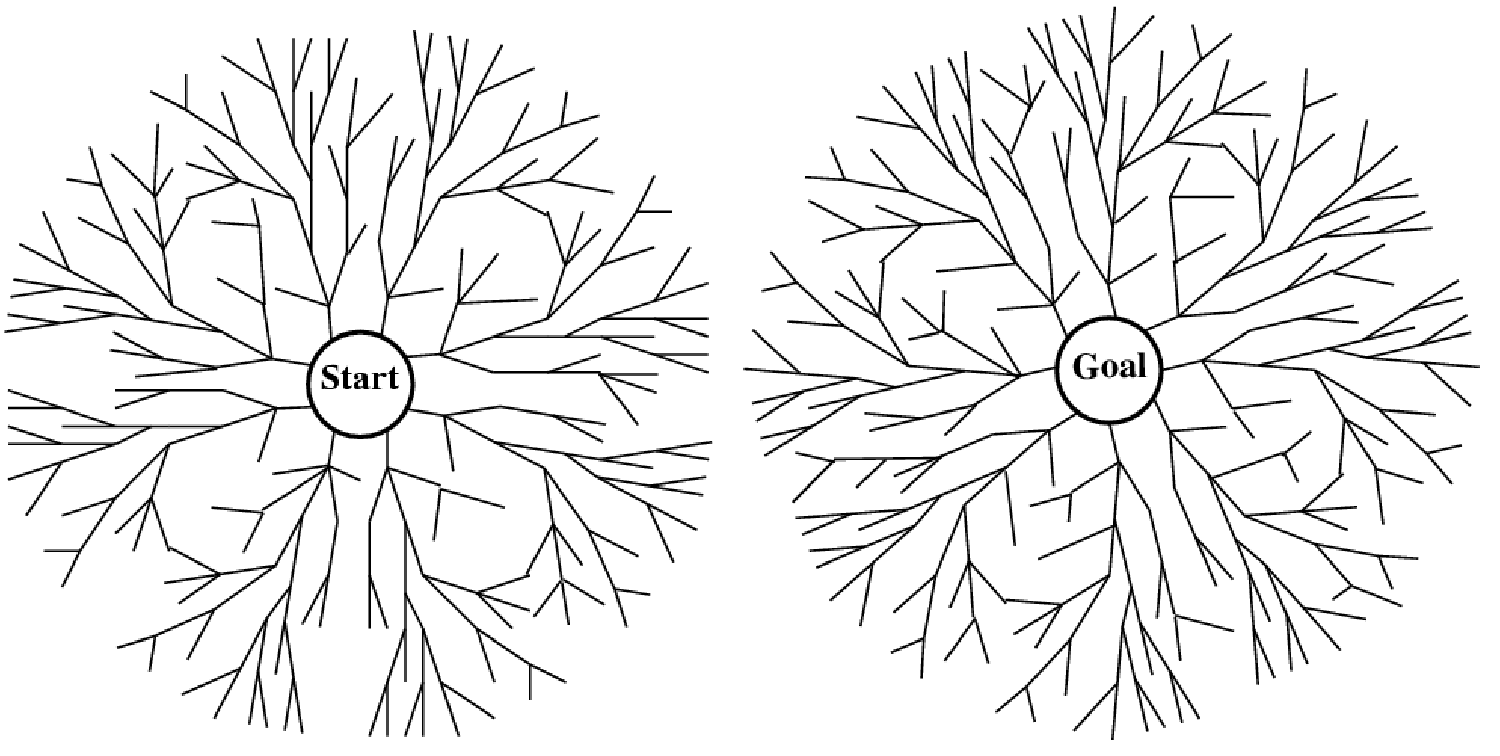
- Repeated expansions is a bigger issue for DFS than for BFS or IDDFS
  - Trying to remember all previously expanded nodes and comparing the new nodes with them is infeasible
  - Space becomes exponential
  - duplicate checking can also be exponential

- Partial reduction in repeated expansion can be done by
  - Checking to see if any children of a node n have the same state as the parent of n
  - Checking to see if any children of a node n have the same state as any ancestor of n (at most d ancestors for n—where d is the depth of n)

Forwards *vs.* Backwards



vs. Bidirectional

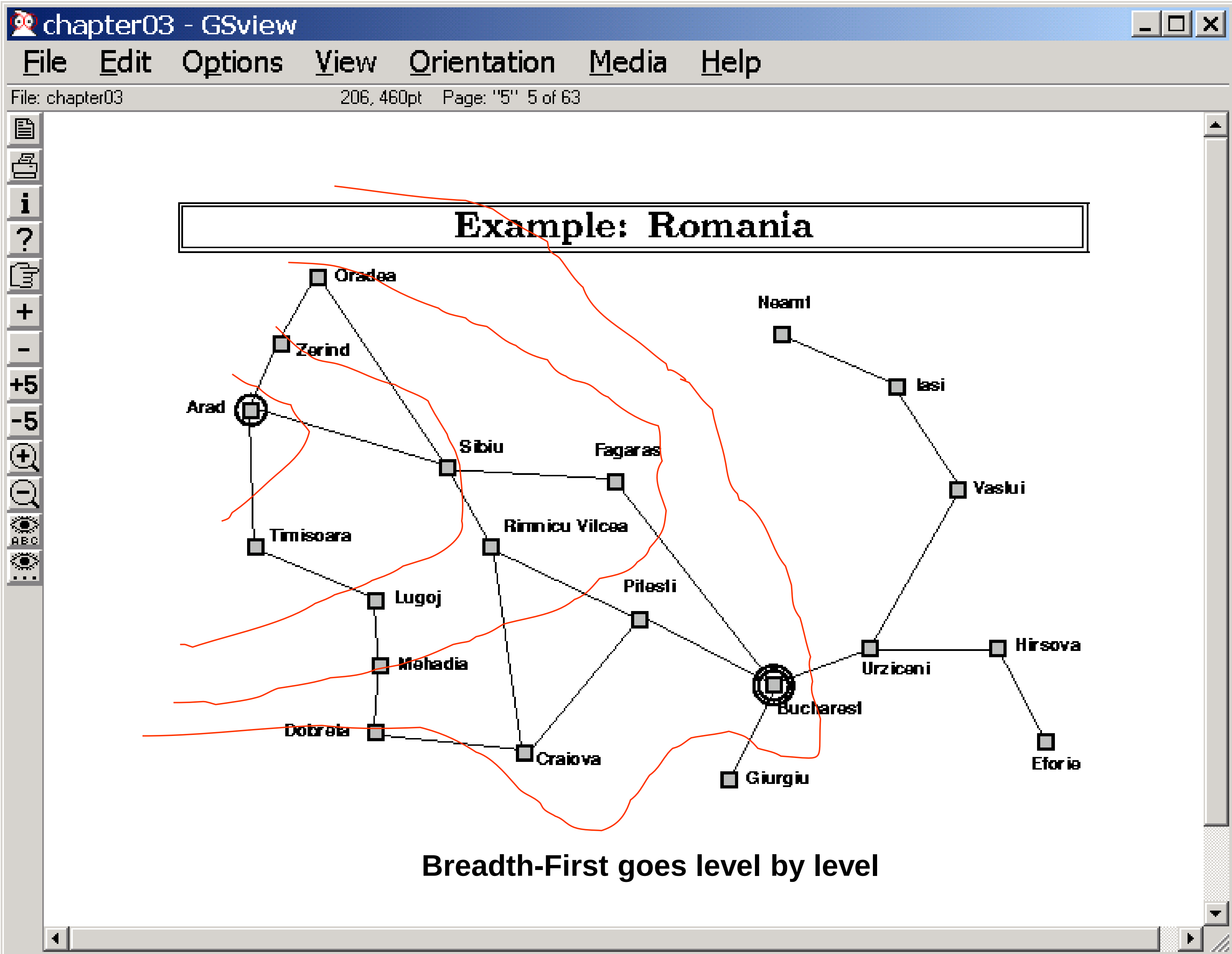


When is bidirectional search applicable?

- **Generating predecessors is easy**
- **Only 1 (or few) goal states**

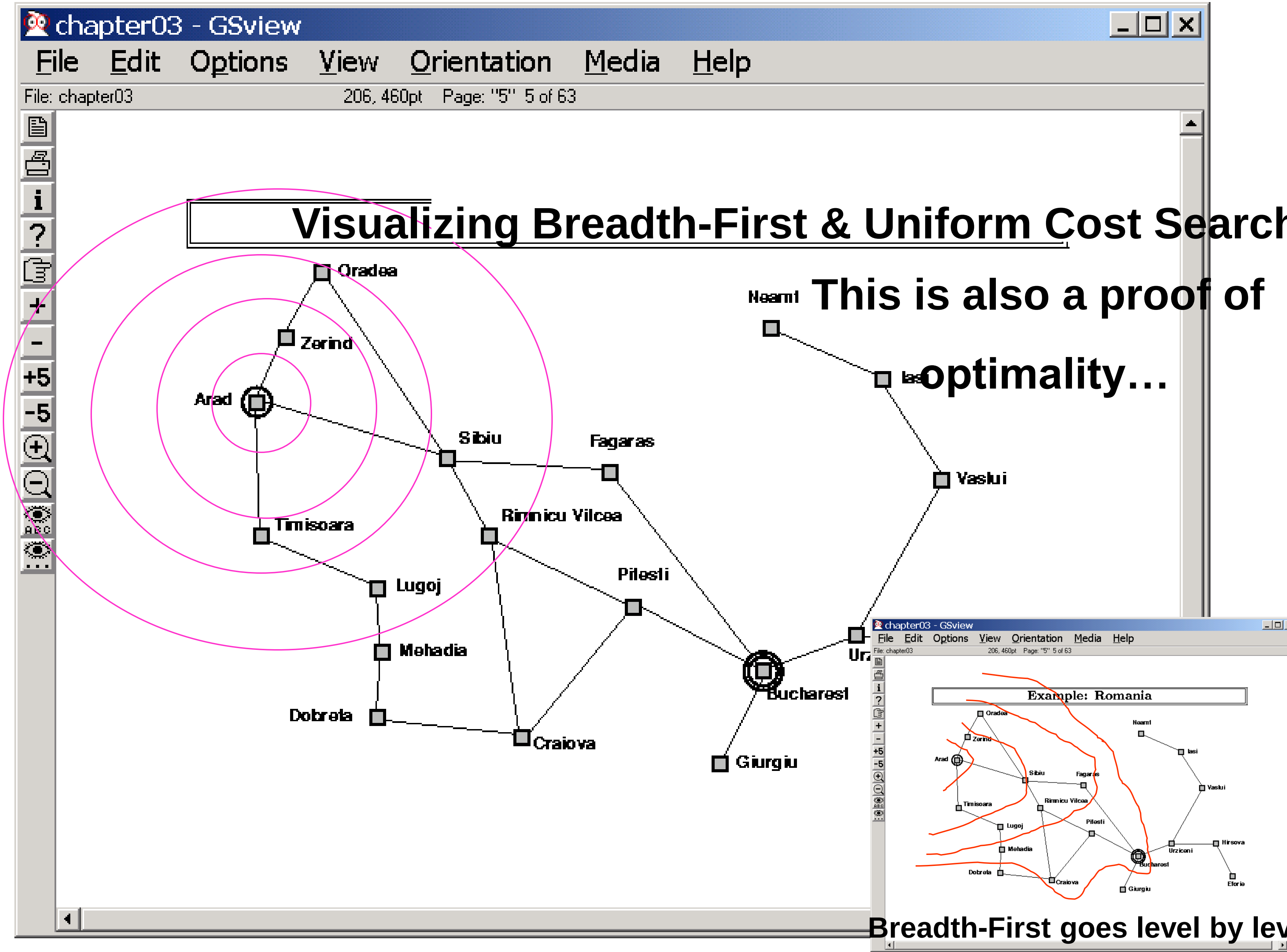
Bidirectional search

- Complete? Yes
- Time?
  - $O(b^{d/2})$
- Space?
  - $O(b^{d/2})$
- Optimal?
  - Yes if uniform cost search used in both directions



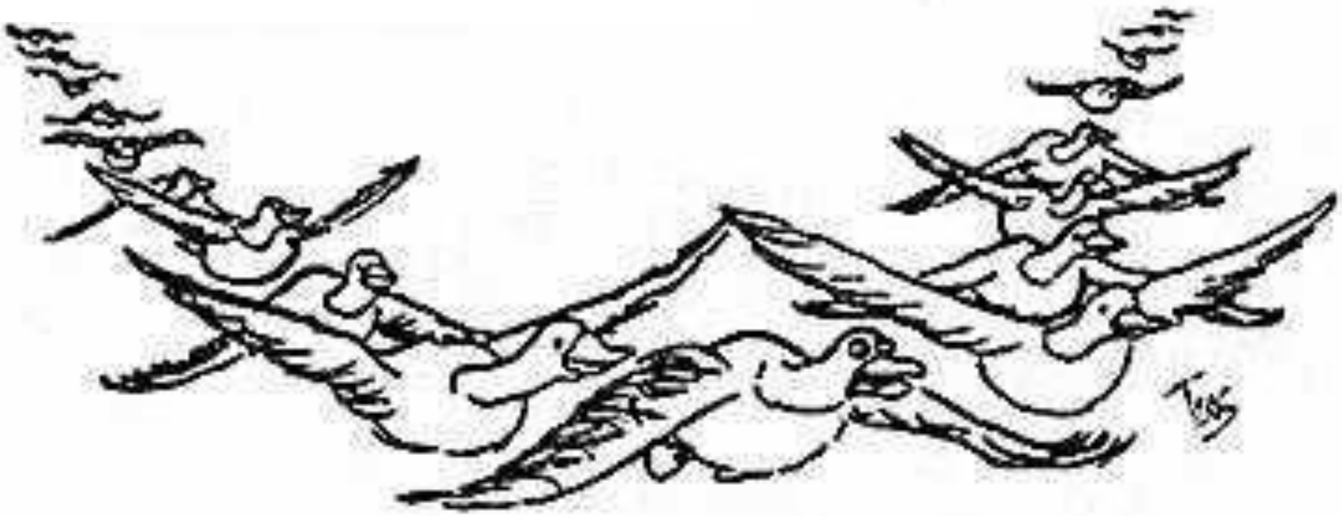
Breadth-First goes level by level

Visualizing Breadth-First & Uniform Cost Search



This is also a proof of optimality…

Breadth-First goes level by leve



"The problem is, I don't feel that I have any real direction in life."

Problem

- All these methods are slow (blind)
- Solution → add guidance ("heuristic estimate")
  → "informed search"