Uninformed Search

Chapter 3

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

Agent's Knowledge Representation

Type	State representation	Focus
Atomic	States are indivisible; No internal structure	Search on atomic states;
Propositional (aka Factored)	States are made of state variables that take values (Propositional or Multi-valued or Continuous)	Search+inference in logical (prop logic) and probabilistic (bayes nets) representations
Relational	States describe the objects in the world and their inter-relations	Search+Inference in predicate logic (or relational prob. Models)
First-order	+functions over objects	Search+Inference in first order logic (or first order probabilistic models)

Illustration with Vacuum World

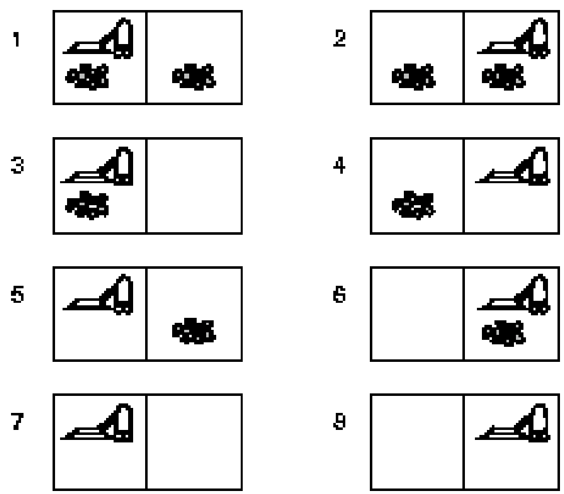
Atomic:

S1, S2…. S8

state is seen as an indivisible snapshot

All Actions are SXS matrices..

If you add a second roomba the state space *doubles*



Propositional/Factored:

States made up of 3 state variables

Dirt-in-left-room T/F

Dirt-in-right-room T/F

Roomba-in-room L/R

Each state is an assignment of Values to state variables

2^3 Different states

Actions can just mention the variables they affect

Note that the representation is compact (logarithmic in the size of the state space)

If you add a second roomba, the Representation increases by just one More state variable.

If you want to consider "noisiness" of rooms, we need *two* variables, one for Each room

Relational:

World made of objects: Roomba; L-room, R-room

Relations: In (<robot>, <room>); dirty(<room>)

If you add a second roomba, or more rooms, only the objects increase.

If you want to consider noisiness, you just need to add one other relation

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]

What is Search?

- Search is a class of techniques for systematically finding or constructing solutions to problems.

- Example technique: generate-and-test.
- Example problem: Combination lock.

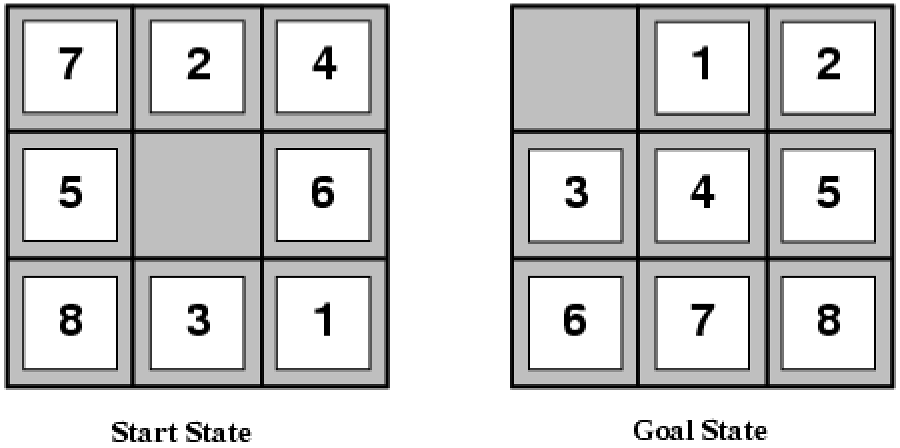
1. Generate a possible solution.
2. Test the solution.
3. If solution found THEN done ELSE return to step 1.

Why is search interesting?

- Many (all?) AI problems can be formulated as search problems!

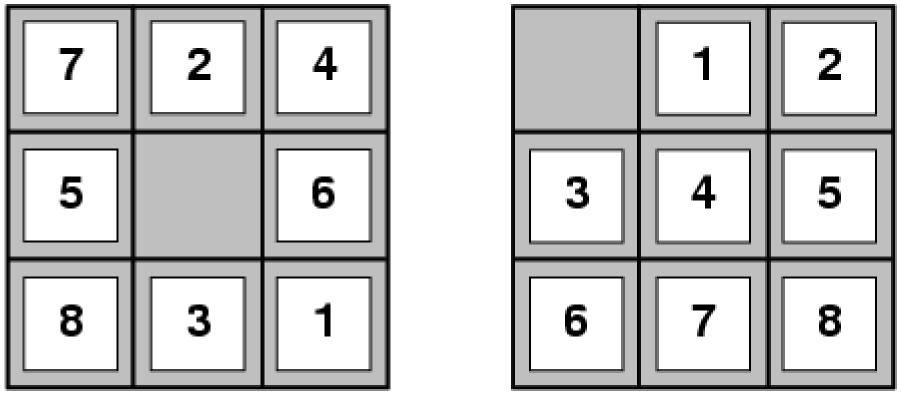
- Examples:
  - Path planning
  - Games
  - Natural Language Processing
  - Machine learning
  - …

Example: The 8-puzzle



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

Example: The 8-puzzle

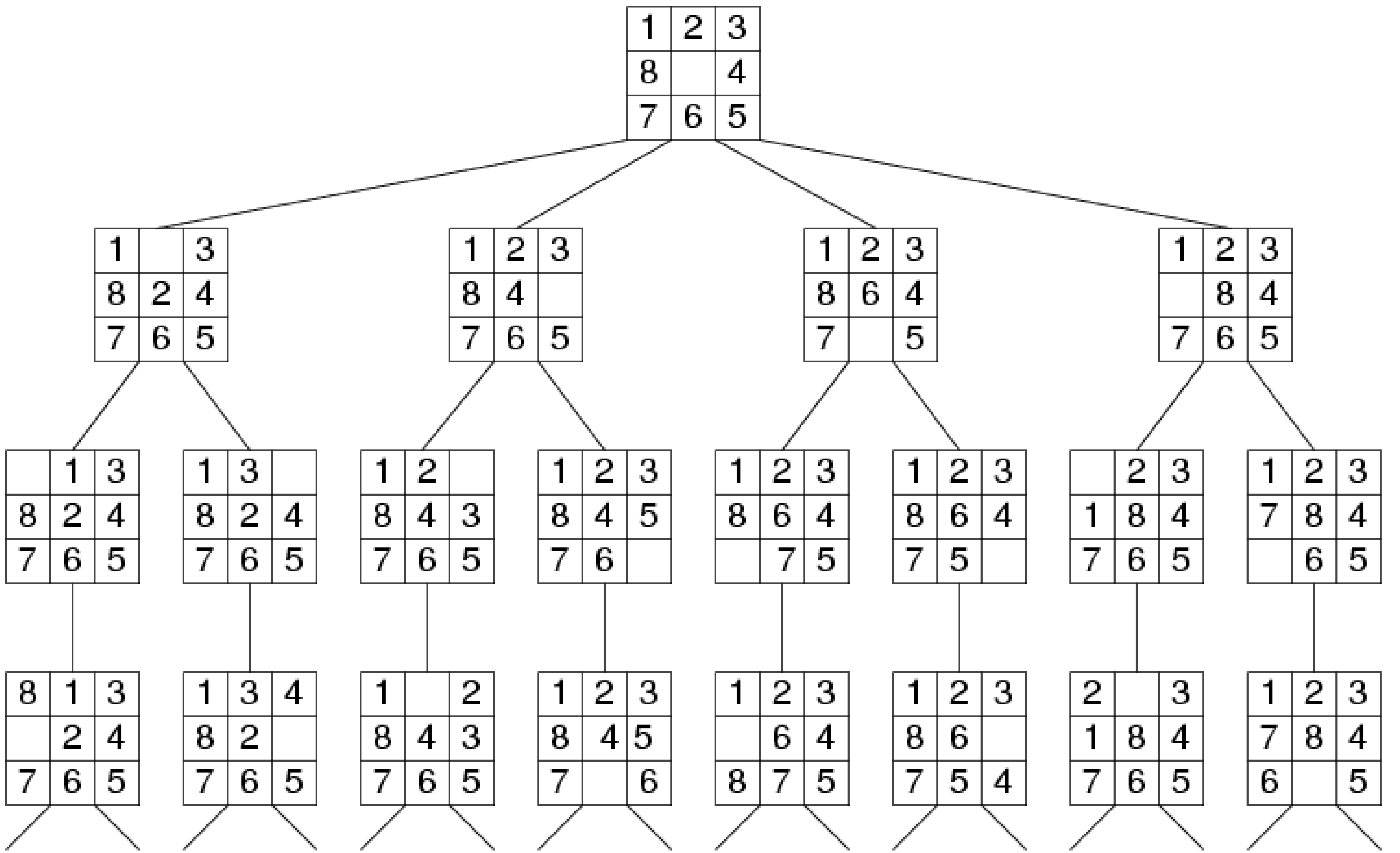


Start State Goal State

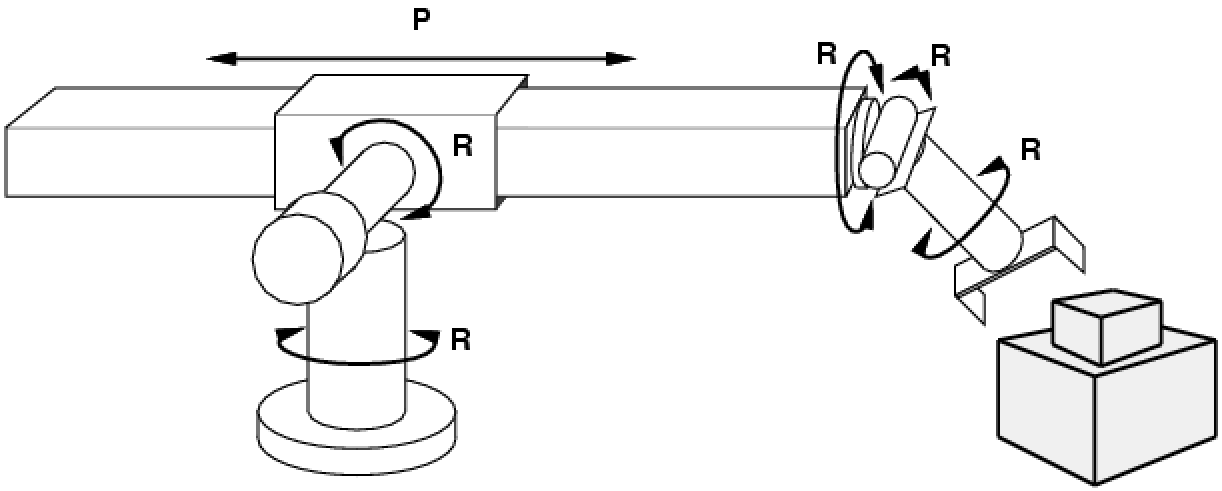
- states? locations of tiles
- actions? move blank left, right, up, down
- goal test? = goal state (given)
- path cost? 1 per move
-

- [Note: optimal solution of *n*-Puzzle family is NP-hard]

Search Tree Example:
Fragment of 8-Puzzle Problem Space



Example: robotic assembly



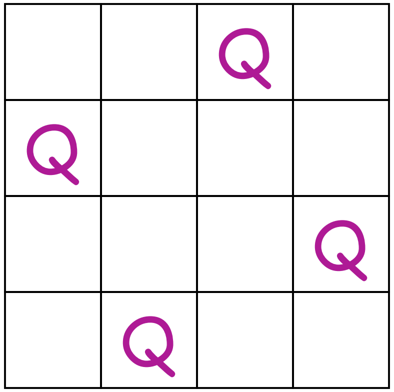
- states?: real-valued coordinates of robot joint angles parts of the object to be assembled
-
- actions?: continuous motions of robot joints
-
- goal test?: complete assembly
-
- path cost?: time to execute
-

Example: Romania

- On holiday in Romania; currently in Arad.
- Flight leaves tomorrow from Bucharest
-
- Formulate goal:
  - be in Bucharest
  -
- Formulate problem:
  - states: various cities
  - actions: drive between cities
  -
- Find solution:
  - sequence of cities, e.g., Arad, Sibiu, Fagaras, Bucharest
  -

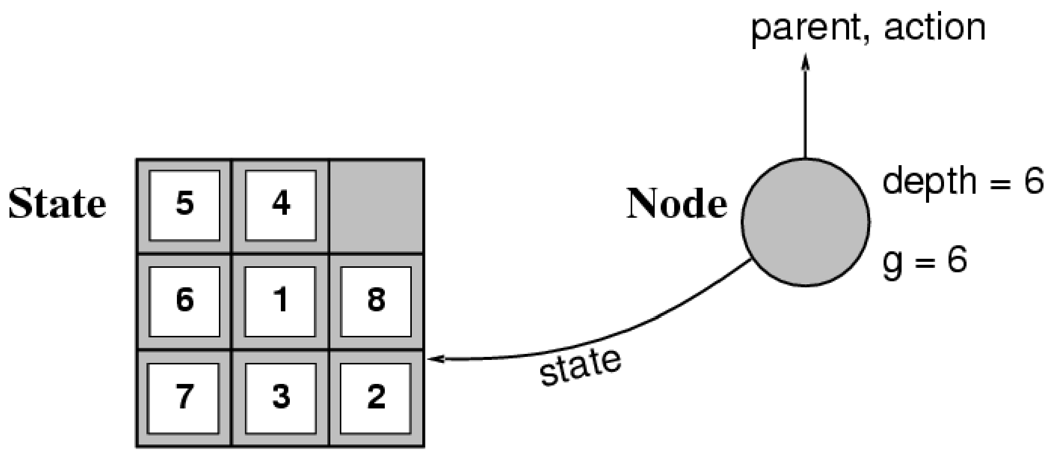
Example: N Queens

- Input:
  - Set of states
  - Operators [and costs]
  - Start state
  - Goal state (test)
- Output



Implementation: 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



- The `Expand` function creates new nodes, filling in the various fields and using the `SuccessorFn` of the problem to create the corresponding states.
-

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?

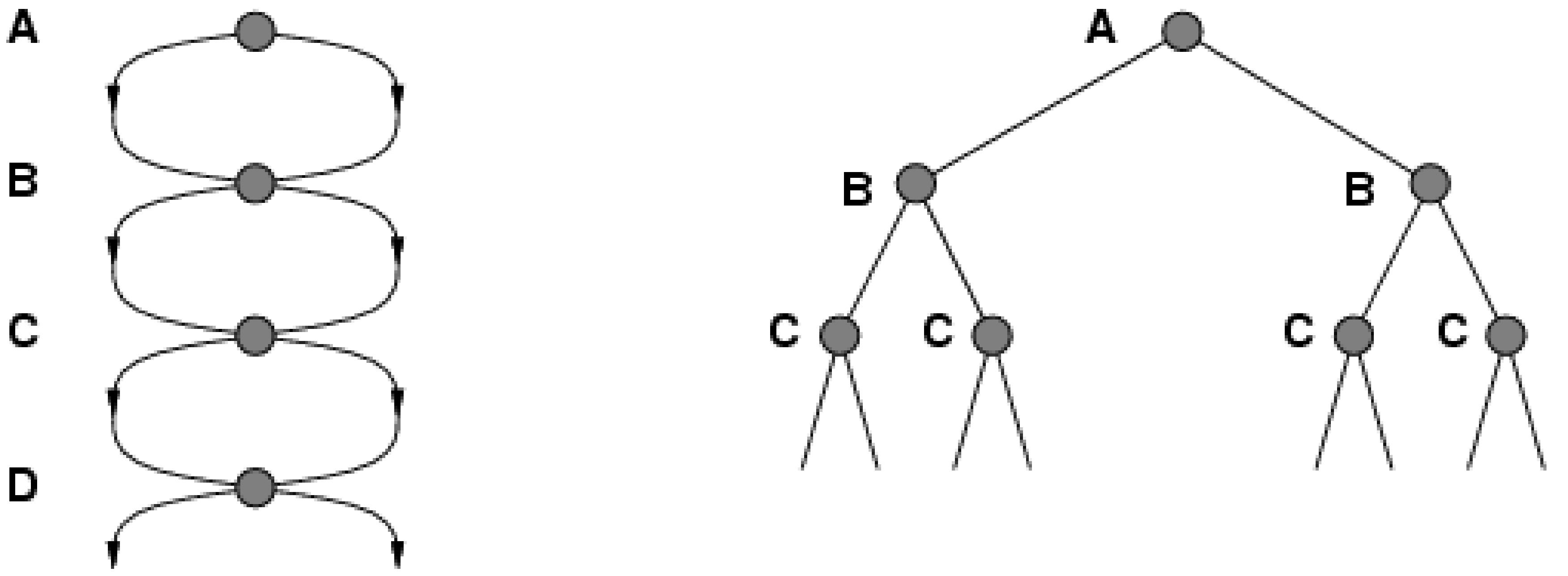
- Time and space complexity are measured in terms of
  - *b:* maximum branching factor of the search tree
  - *d:* depth of the least-cost solution
  - *m*: maximum depth of the state space (may be ∞)

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

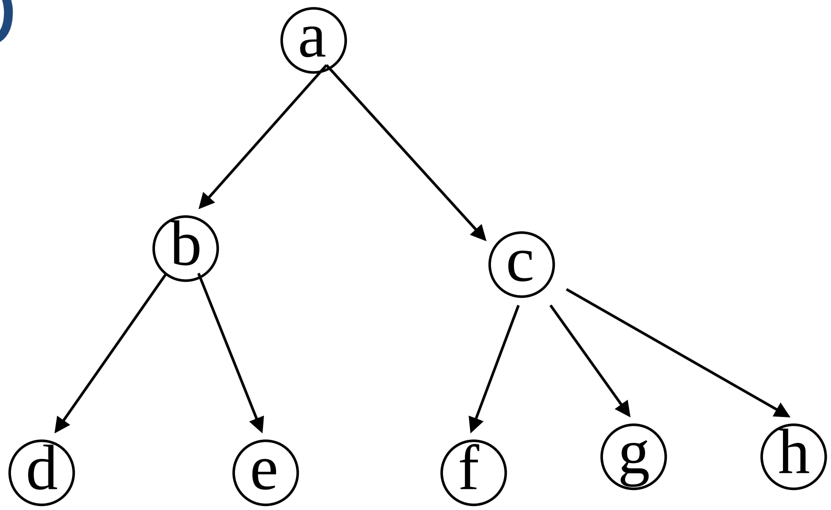
Repeated states

- Failure to detect repeated states can turn a linear problem into an exponential one!



Depth First Search

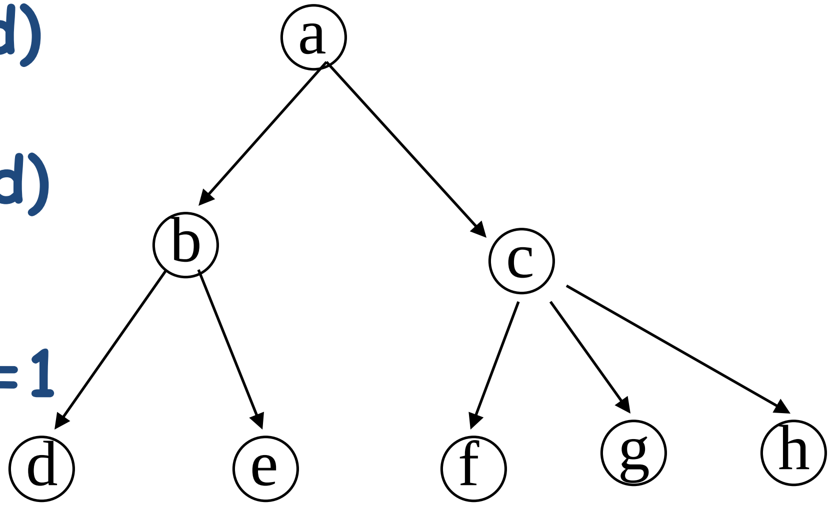
- Maintain stack of nodes to visit
- Evaluation
  - Complete? No
  - Time Complexity? O(b^m)
  - Space Complexity? O(bm)



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

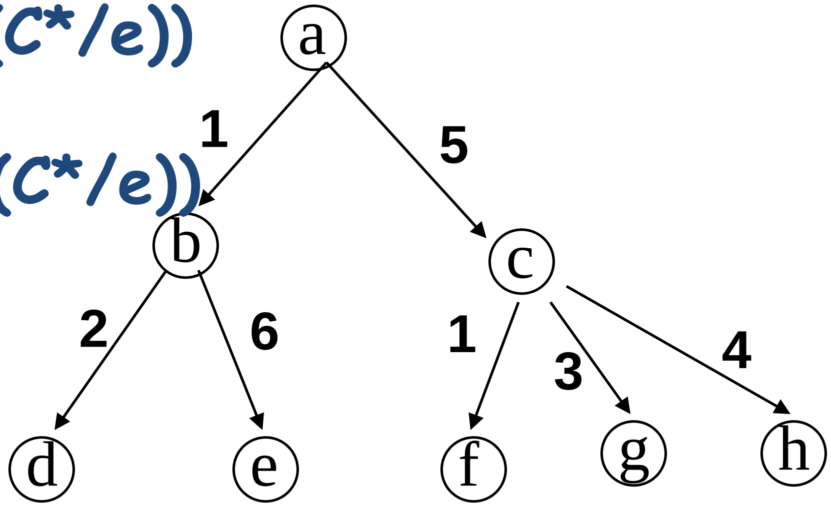
Breadth First Search: shortest first

- 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



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

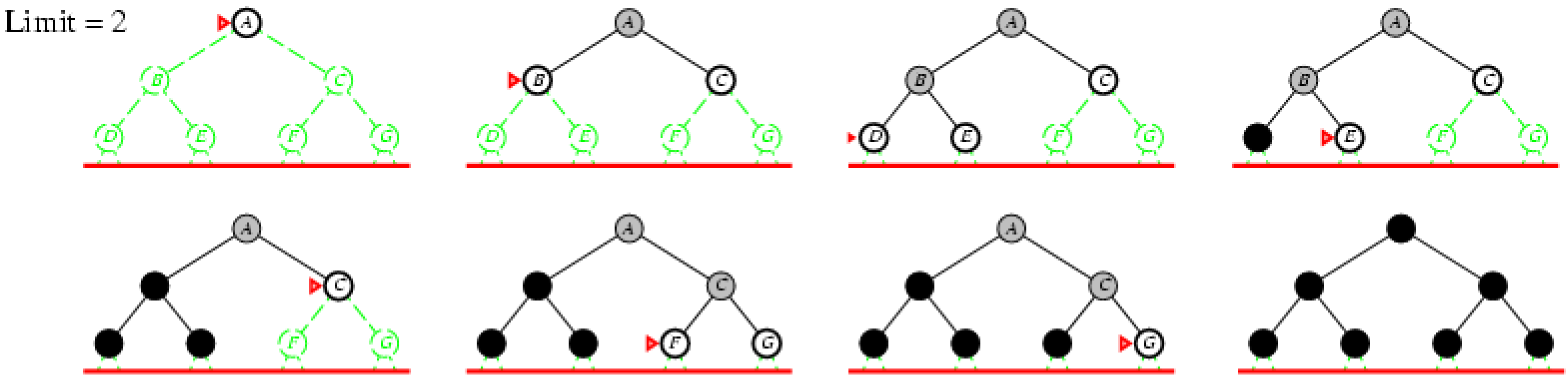
Iterative deepening search *l* =0

Limit = 0

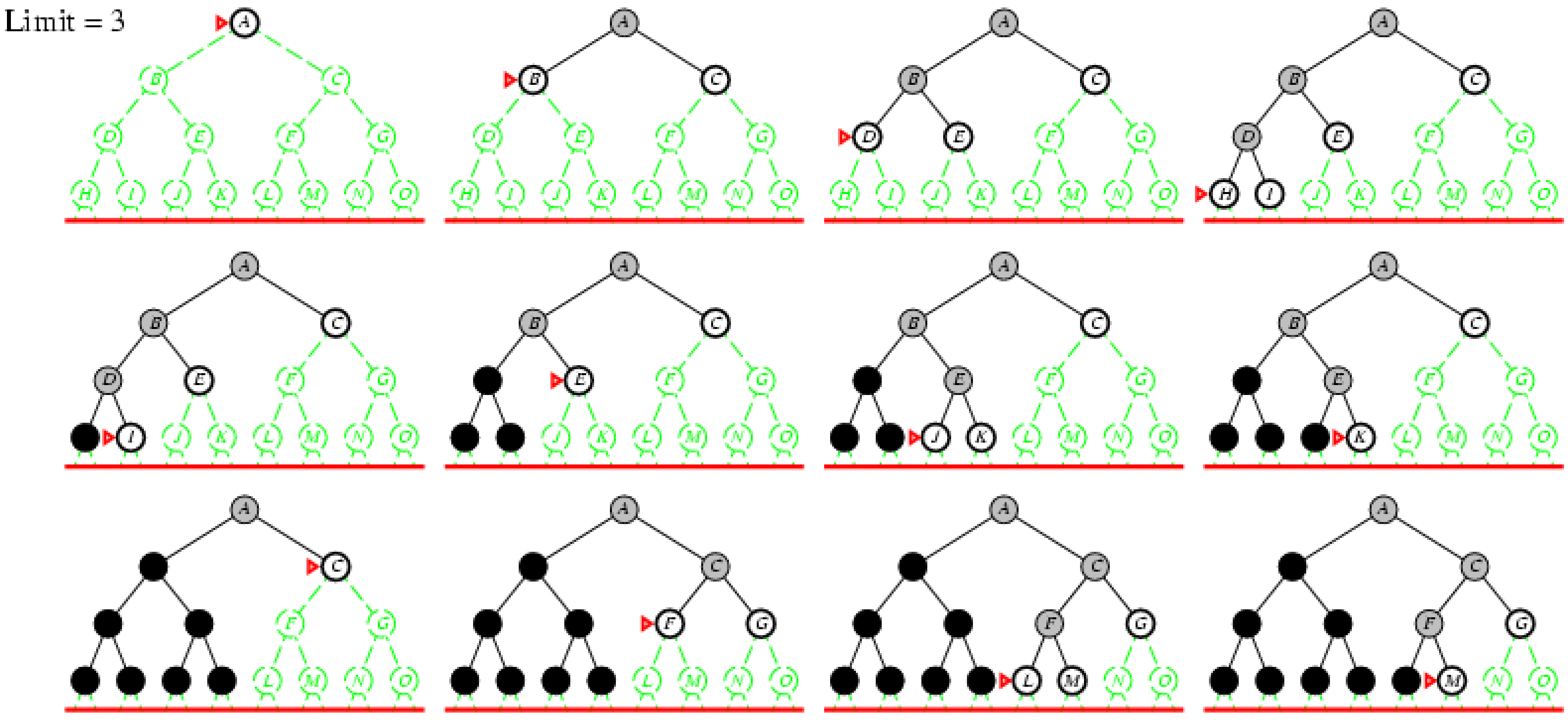
Iterative deepening search *l* =1

Limit = 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

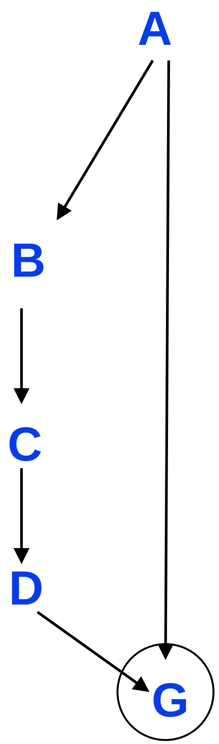
- Complete?
  - Yes
- Time?
  - $(d+1)b^0 + d\,b^1 + (d-1)b^2 + \ldots + b^d = O(b^d)$
- Space?
  - $O(bd)$
- Optimal?
  - Yes, if step cost = 1
  - Can be modified to explore uniform cost tree (iterative lengthening)
- Systematic?

Cost of Iterative Deepening

b	ratio ID to DLS
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

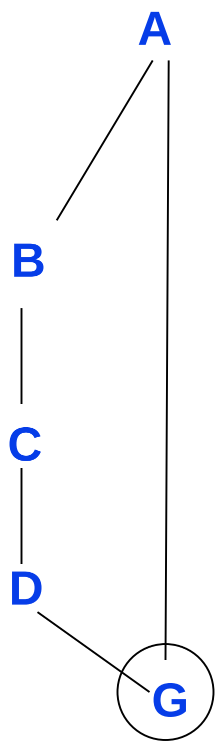


BFS: A,B,G

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…

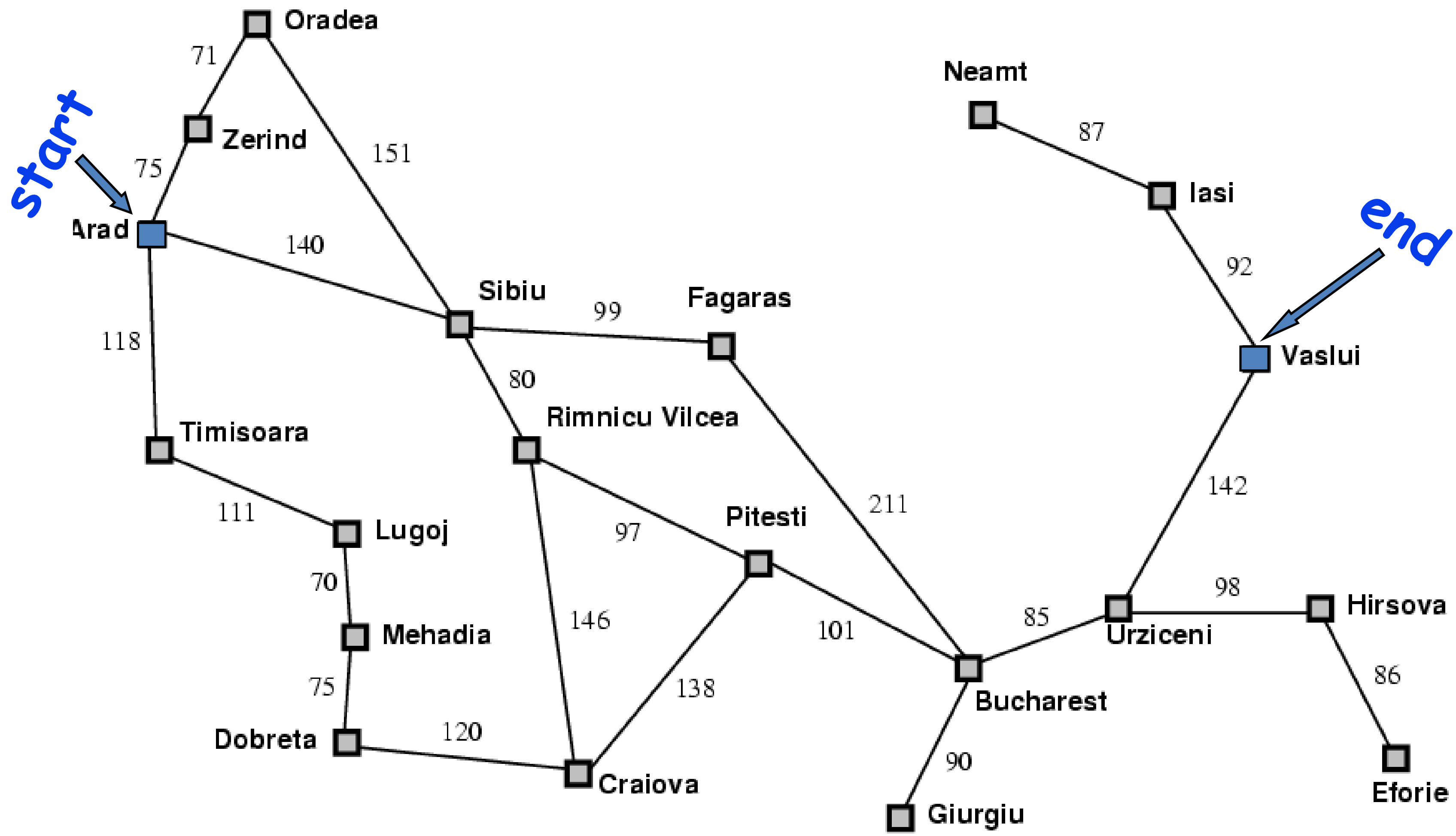
Cycles galore…

Graph (instead of tree) Search: Handling repeated nodes

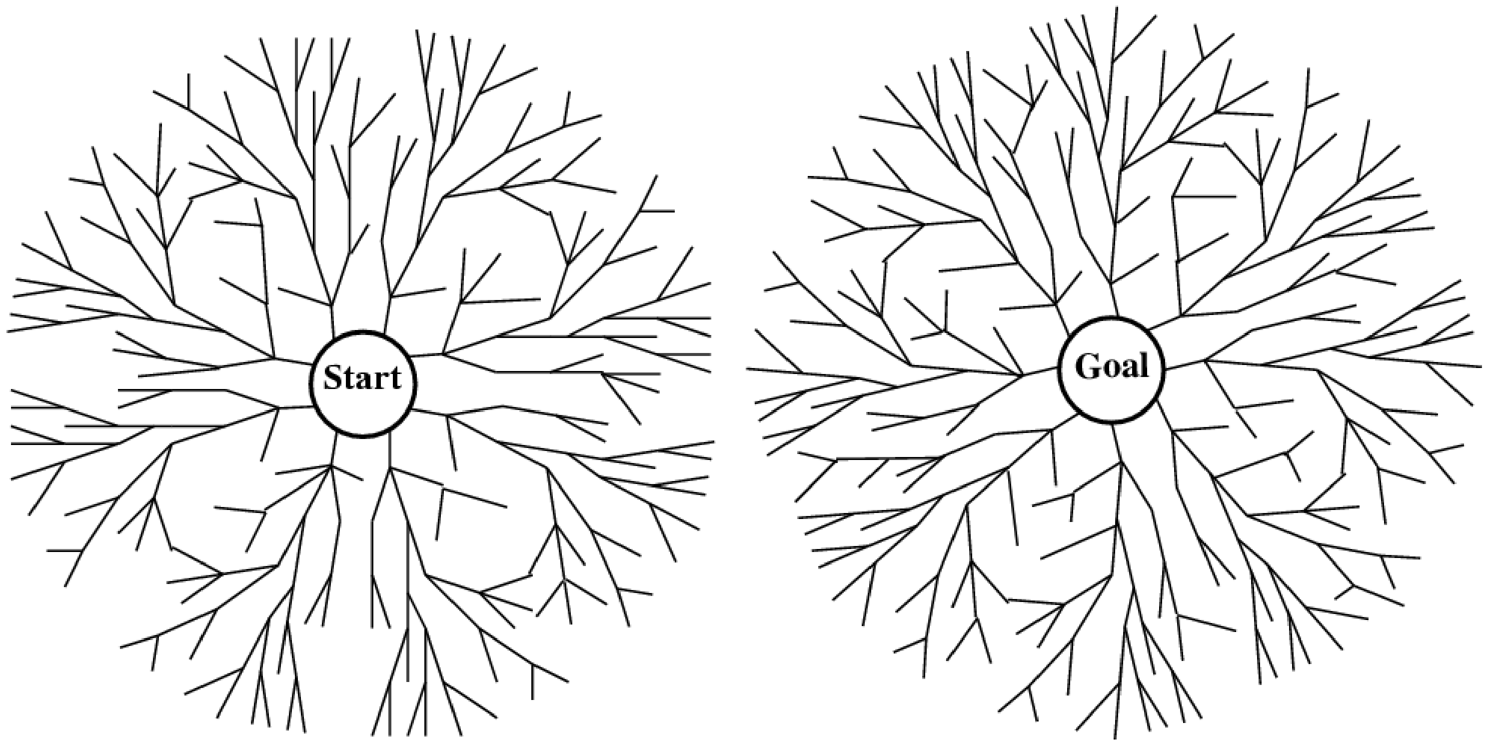
- Repeated expansions is a bigger issue for DFS than for BFS or IDDFS
  - Trying to remember all previously expanded nodes and comparing the new nodes with them is infeasible
  - Space becomes exponential
  - duplicate checking can also be expensive

- 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

chapter03 - GSview

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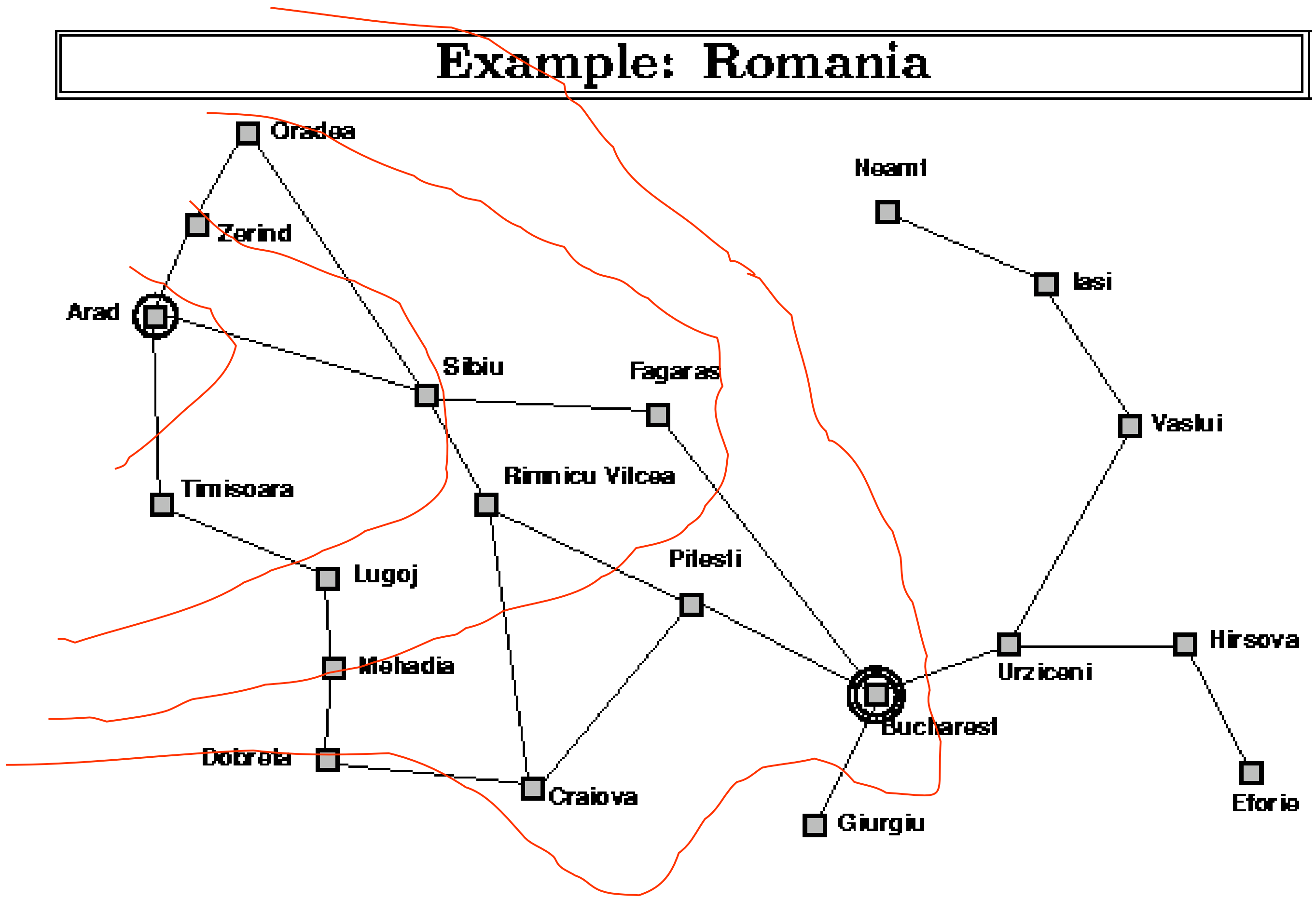
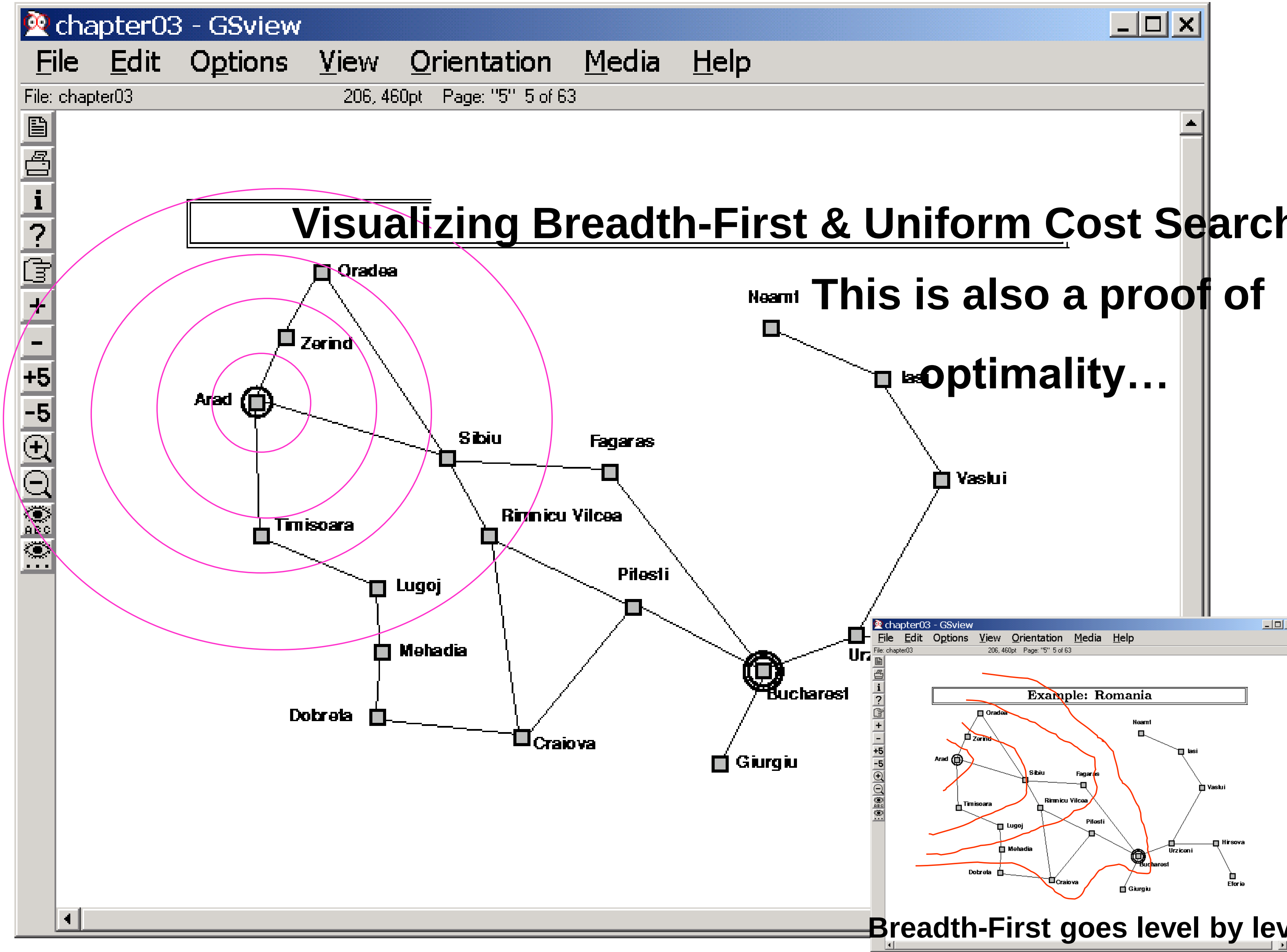
Example: Romania



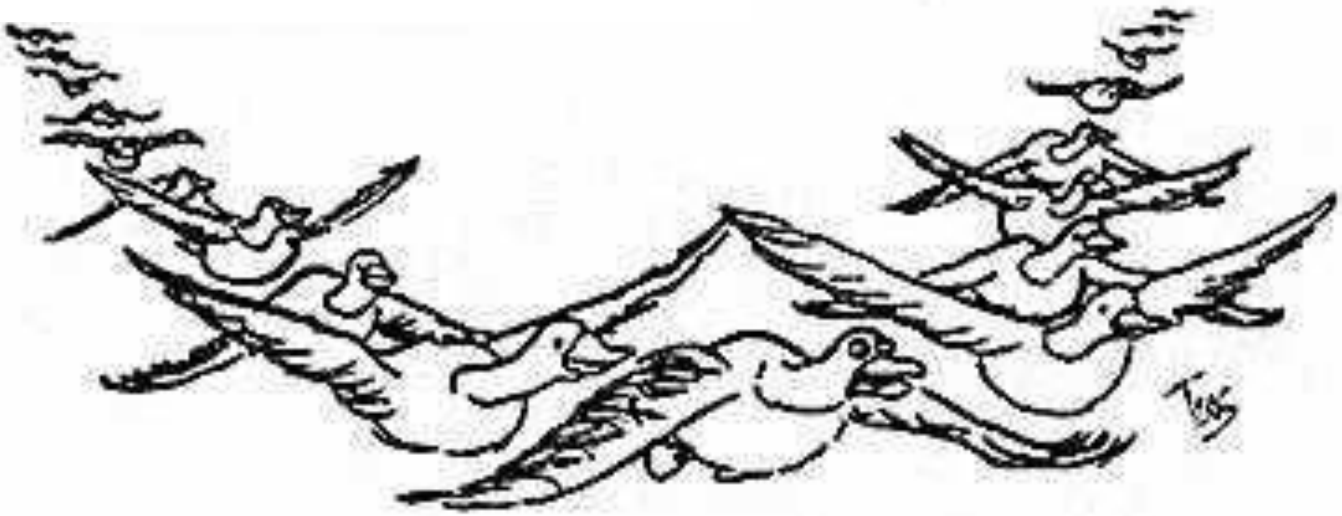
Breadth-First goes level by level

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"