COMP 472 Artificial Intelligence
State Space Search part #3
Uninformed Search video #2

- Russell & Norvig – Section 3.4
- see also: https://www.javatpoint.com/ai-uninformed-search-algorithms

Today

1. State Space Representation
2. State Space Search
   a) Overview

   b) Uninformed search
      1. Breadth-first and Depth-first
      2. Depth-limited Search
      3. Iterative Deepening
      4. Uniform Cost
   c) Informed search
      1. Intro to Heuristics
      2. Hill climbing
      3. Best-First
      4. Algorithms A & A*
      5. More on Heuristics
   d) Summary

Uninformed VS Informed Search

- Uninformed search
  - all nodes are equally promising, so we explore them systematically
  - aka: systematic/blind/brute force search
  - many algorithms:
    1. Breadth-first search
    2. Depth-first seach
    3. Uniform-cost search
    4. Depth-limited search
    5. Iterative deepening search
    6. ...

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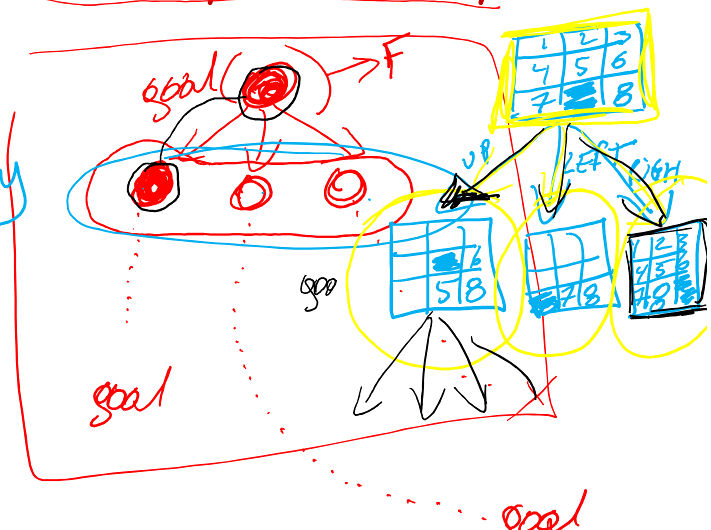
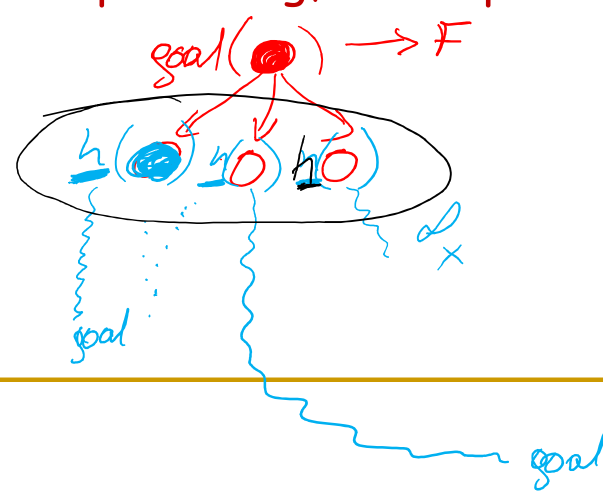
video today



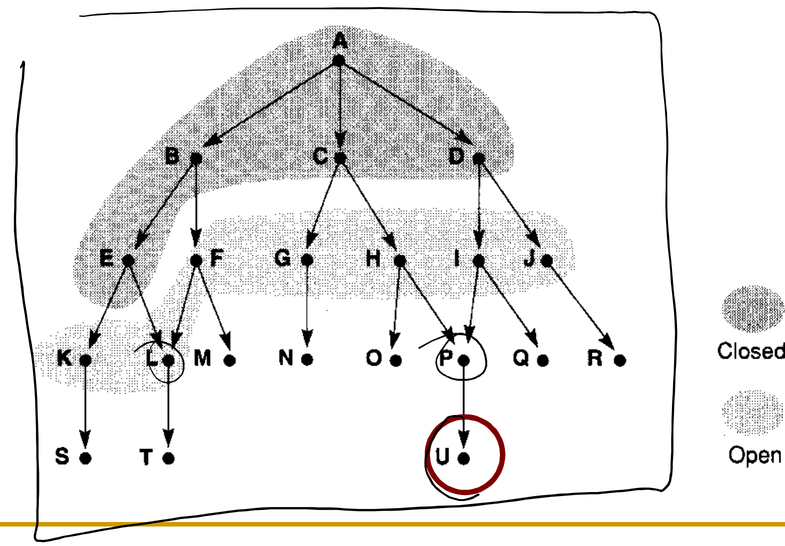
- Informed search (heuristic search)
  - we try to identify which nodes *seem* more promising, and explore these first
  - many algorithms:
    1. Hill climbing
    2. Gready Best-First search
    3. Algorithms A and A*
    4. ...



Data Structures

- Most search strategies require:
  - ***open list*** (aka the frontier) To-DO
    - lists generated nodes not yet expanded
    - order of nodes controls order of search
  - ***closed list*** (aka the explored set)
    - stores all the nodes that have already been visited (to avoid cycles).
- ex:

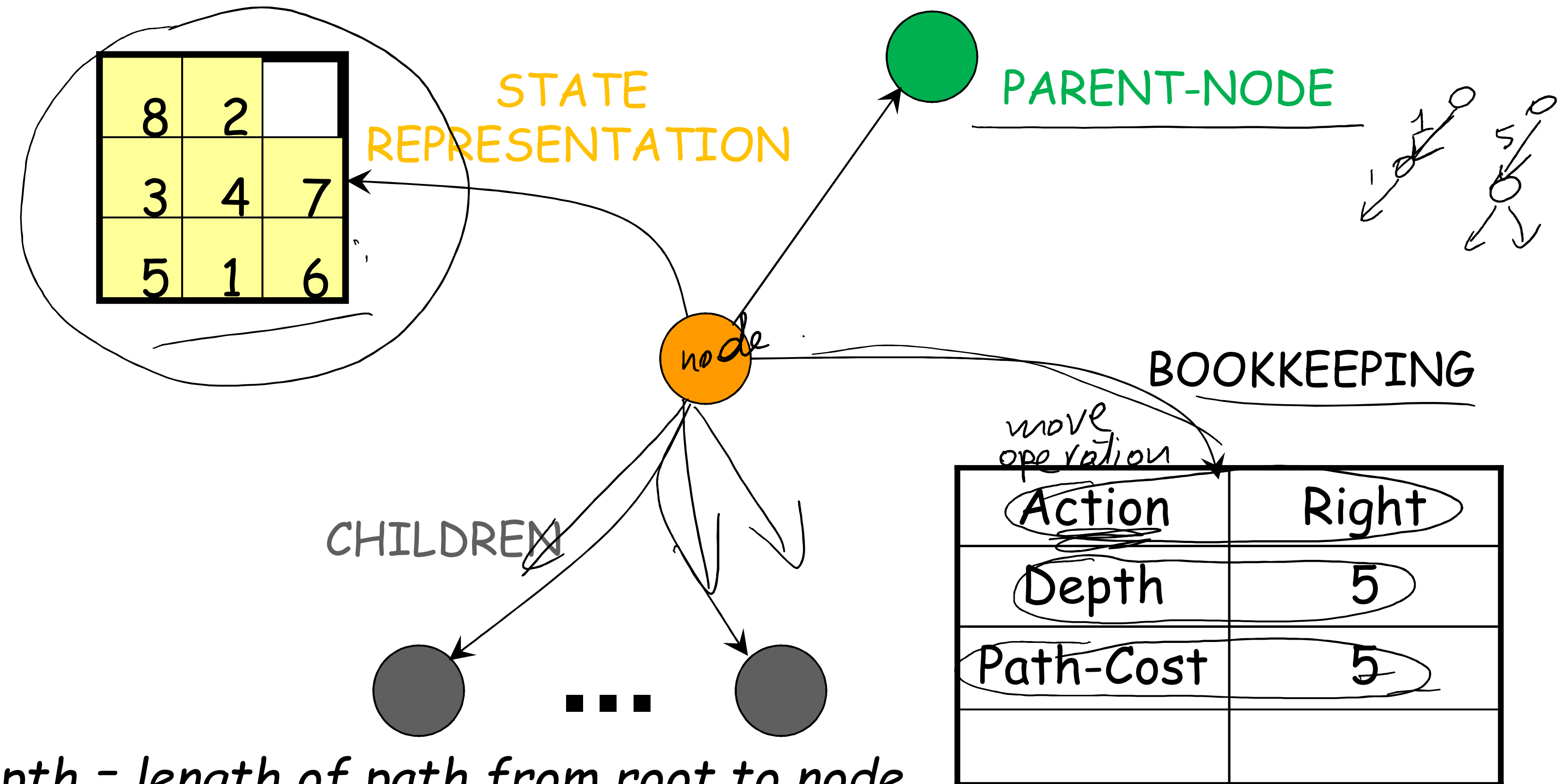
Closed = [A, B, C, D, E]
Open = [F, G, H, I, J, K, L]



source: G. Luger (2005)

Data Structures

- state space representation: To trace back the solution path after the search, each node in the lists contain:



Depth = length of path from root to node

robotics.stanford.edu/~latombe/cs121/2003/home.htm

Generic Search Algorithm

TO-DO

1. Initialize the open list with the initial node s_o (top node)
2. Initialize the closed list to empty

   done / visited
3. Repeat
   a) If the open list is empty, then exit with failure.
   b) Else, take the first node s from the open list.
   c) If s is a goal state, exit with success. Extract the solution path from s to s_o
   d) Else, insert s in the closed list (s has been visited /expanded)
   e) Insert the successors of s in the open list in a certain order if they are not already in the closed and/or open lists (to avoid cycles)

Notes:

- The order of the nodes in the open list depends on the search strategy

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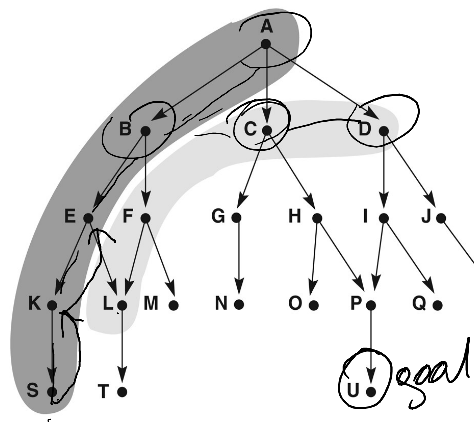
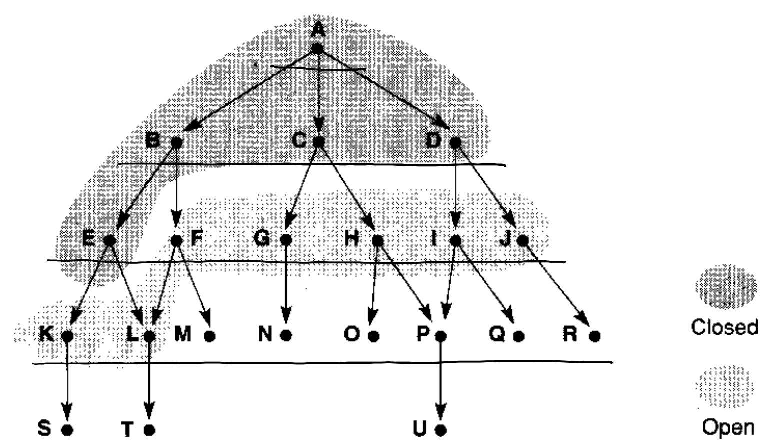
Depth-first vs Breadth-first Search

- Depth-first (DFS):
  - visit successors before siblings
  - Open list is a stack



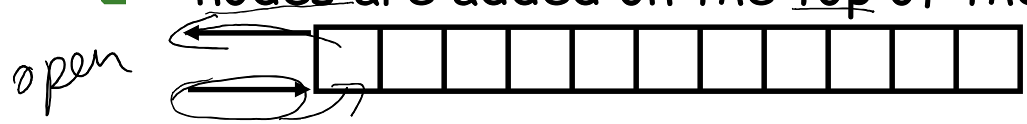
- Breadth-first (BFS):
  - visit siblings before successors
  - ie. visit level-by-level
  - open list is a queue



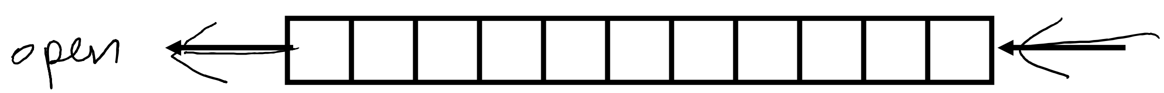
source: G. Luger (2005)

DFS and BFS

- DFS and BFS differ only in the way they order nodes in the open list:
  - DFS uses a stack:
    - nodes are added on the top of the open list.



  - BFS uses a queue:
    - nodes are added at the end of the list.



Breadth-First Search

```
begin
   open := [Start];                                              % initialize
   closed := [ ];
   while open ≠ [ ] do                                           % states remain
      begin
         remove leftmost state from open, call it X;
            if X is a goal then return SUCCESS                   % goal found
               else begin
                  generate children of X;
                  put X on closed;
                  discard children of X if already on open or closed;   % loop check
                  put remaining children on right end of open           % queue
               end
      end
   return FAIL                                                   % no states left
end.
```

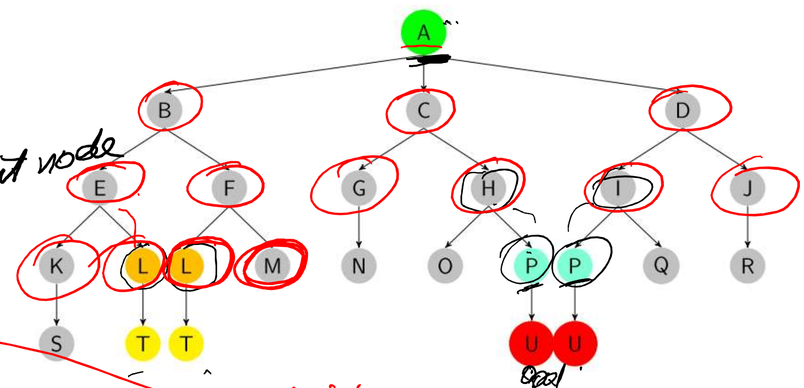
source: G. Luger (2005)

Breadth-First Search Example

- BFS: (open is a queue)

Assume U is goal state

name of node
name of parent node



1. open = [A-null] closed = []
2. open = [B-A C-A D-A] closed [A]
3. open = [C-A D-A E-B F-B] closed = [B A]
4. open = [D-A E-B F-B G-C H-C] closed = [C B A]
5. open = [E-B F-B G-C H-C I-D J-D] closed = [D C B A]
6. open = [F-B G-C H-C I-D J-D K-E L-E] closed = [E D C B A]
7. open = [G-C H-C I-D J-D K-E L-E M-F] *as L is already in open* closed = [F E D C B A]
8. and so on until either U is found or open = []

visit ⇒ run goal function

search path = A B C D E F G H I J K L M N … U // closed list

solution path = A C H P U with a cost of 4 // extract by following the parent pointer

source: G. Luger (2005)

Depth-First Search

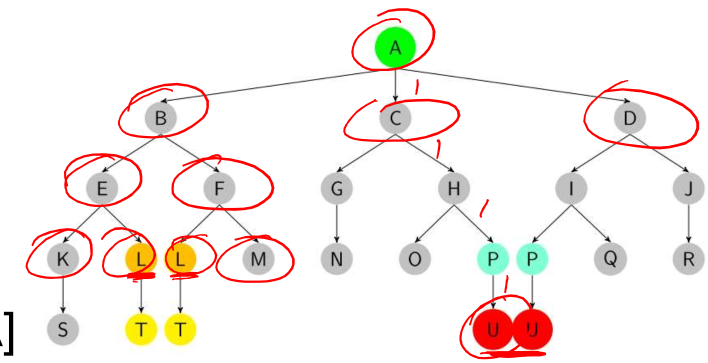
```
begin
   open := [Start];                                                    % initialize
   closed := [ ];
   while open ≠ [ ] do                                                 % states remain
      begin
         remove leftmost state from open, call it X;
         if X is a goal then return SUCCESS                            % goal found
            else begin
               generate children of X;
               put X on closed;
               discard children of X if already on open or closed;    % loop check
               put remaining children on left end of open              % stack
            end
      end;
   return FAIL                                                         % no states left
end.
```

source: *G. Luger (2005)*

Depth-First Search Example

- DFS: (open is a stack)

Assume U is goal state



1. open = [A-null] closed = []
2. open = [B-A C-A D-A] closed [A]
3. open = [E-B F-B C-A D-A] closed = [B A]
4. open = [K-E L-E F-B C-A D-A] closed = [E B A]
5. open = [S-K L-E F-B C-A D-A] closed = [K E B A]
6. open = [L-E F-B C-A D-A] closed = [S K E B A]
7. open = [T-L F-B C-A D-A] closed = [L S K E B A]
8. open = [F-B C-A D-A] closed = [T L S K E B A]
9. open = [M-F C-A D-A] *as L is already on closed* closed = [F T L S K E B A]
10. open = [C-A D-A] closed = [M F T L S K E B A]
11. open = [G-C H-C D-A] closed = [C M F T L S K E B A]

search path = A B E K S L .... U // closed list

solution path = A C H P U with a cost of 4

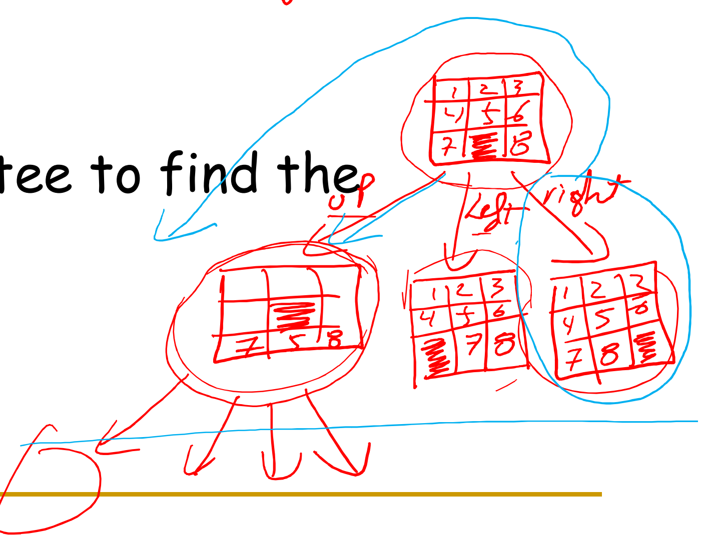
source: G. Luger (2005)

Depth-first vs. Breadth-first

- Breadth-first:
  - advantage: optimal, i.e. will always find shortest solution path
  - disadvantage:
    - high memory requirement as we need to keep all states of a level before expanding to the next level
    - exponential space for states required B^n // B=branching factor, n =level

average # of successors

- Depth-first:
  - advantage: Requires less memory
  - disadvantage: Not optimal (no guarantee to find the shortest path)



300 steps

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Depth-Limited Search

- Compromise for DFS :
  - Do depth-first but
  - with depth cutoff k (depth at which nodes are not expanded)
- Three possible outcomes:
  - Solution withing your k limit :)
  - Failure (no solution)
  - Cutoff (no solution found within cutoff)
- advantage: memory efficient – it's a DFS
- disadvantage: may not find a solution if it is below the cutoff

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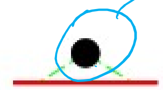
Iterative Deepening

- Combination of BFS and DFS:
  - do depth-first search, but
  - with a maximum depth before going to next level
  - i.e. Repeats depth first search with gradually increasing depth limit~~s~~
- advantage:
  - Requires little memory (fundamentally, it's a depth first)
  - optimal: will find the shortest path (limited depth)
- disadvantage:
  - repeated traversal of the tree top

Iterative Deepening: Example

Limit = 0



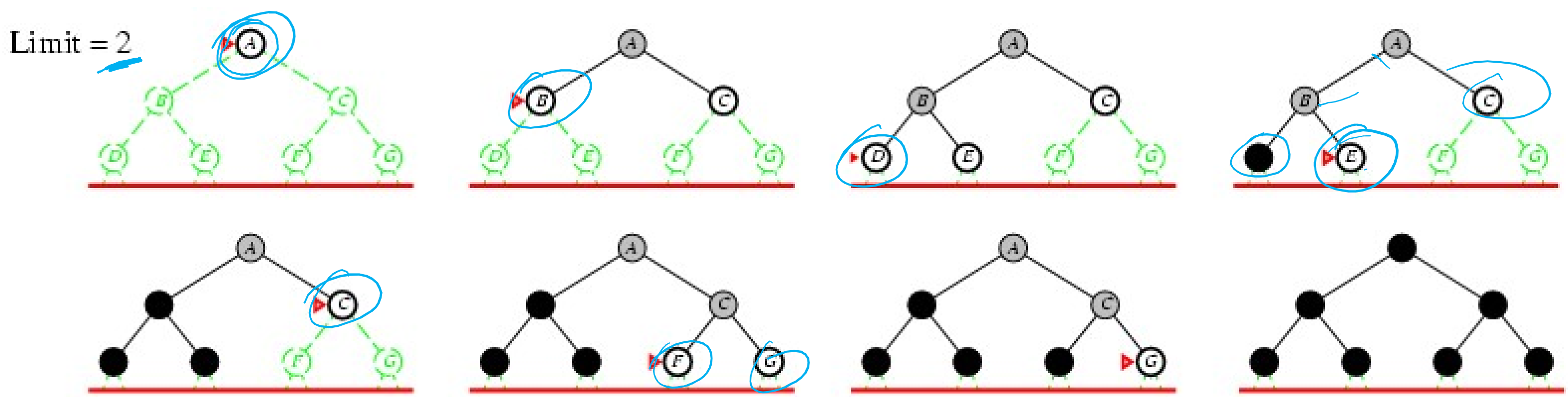
black node
⇒ node has been visited

source: *Russel & Norvig (2003)*

Iterative Deepening: Example

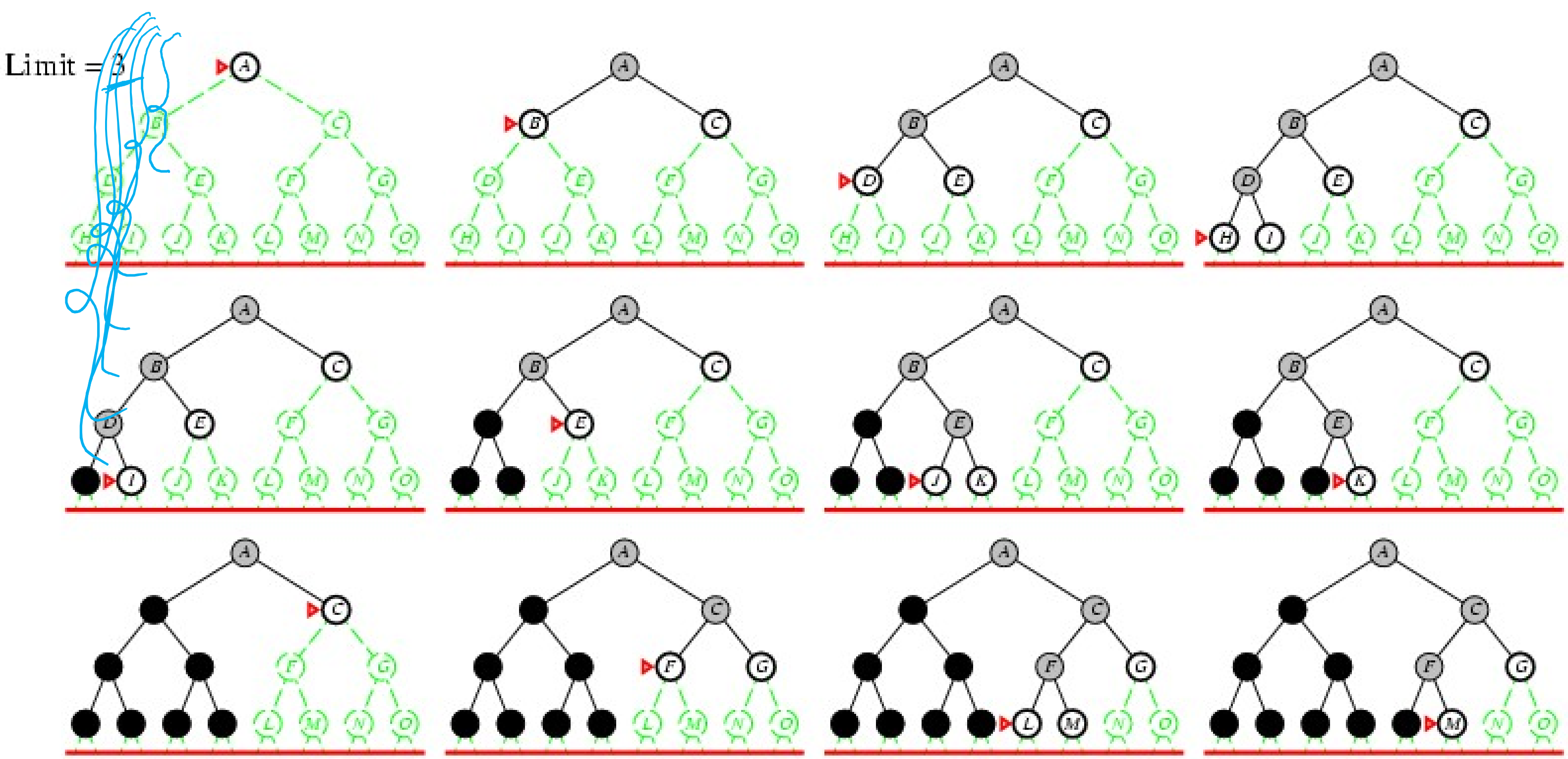
source: Russel & Norvig (2003)

Iterative Deepening: Example



source: *Russel & Norvig (2003)*

Iterative Deepening: Example



source: Russel & Norvig (2003)

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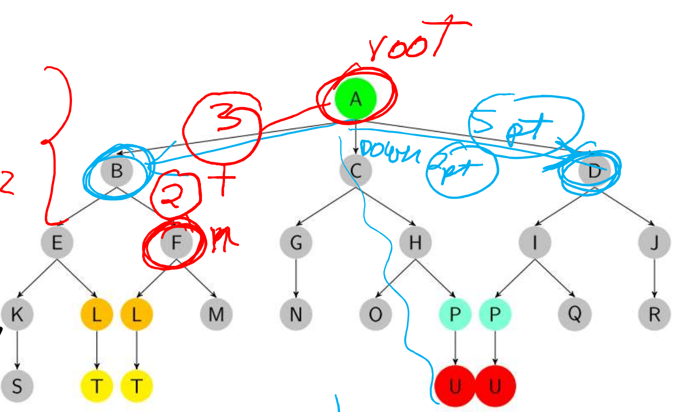
Uniform Cost Search

- all algorithms so far assume that all edges have the same cost
- but what if they have different costs ?
  - eg: move UP -> 2pts but move DOWN -> 1 pt
  - eg: cost(residential road) > cost(commercial road)
- Breadth First Search
  - uses OPEN as a priority queue sorted by the depth of nodes
  - guarantees to find the shortest solution path
- Uniform Cost Search
  - takes the cost of the edge into account
  - uses OPEN as a priority queue sorted by the total cost from the root to node n – *later we will call this g(n)*
  - guarantees to find the lowest cost solution path

$g(n)$

$g(F) = 3+2$



lowest cost of the solution path

Example

node
parent node
total cost from root to n

open | closed

$S_{null\,0}$ | ϕ

P_{S1} E_{S9} D_{S3}
P_{S1} D_{S3} E_{S9} | $S_{null\,0}$

#1 replace old E with new shorter path to E

Q_{P16} D_{S3} E_{S9}
D_{S3} $\cancel{E_{S9}}$ Q_{P16} | $S_{null\,0}$ P_{S1}

B_{D4} C_{D11} E_{D5} Q_{P16}
B_{D4} E_{D5} C_{D11} Q_{P16} | $S_{null\,0}$ P_{S1} D_{S3}

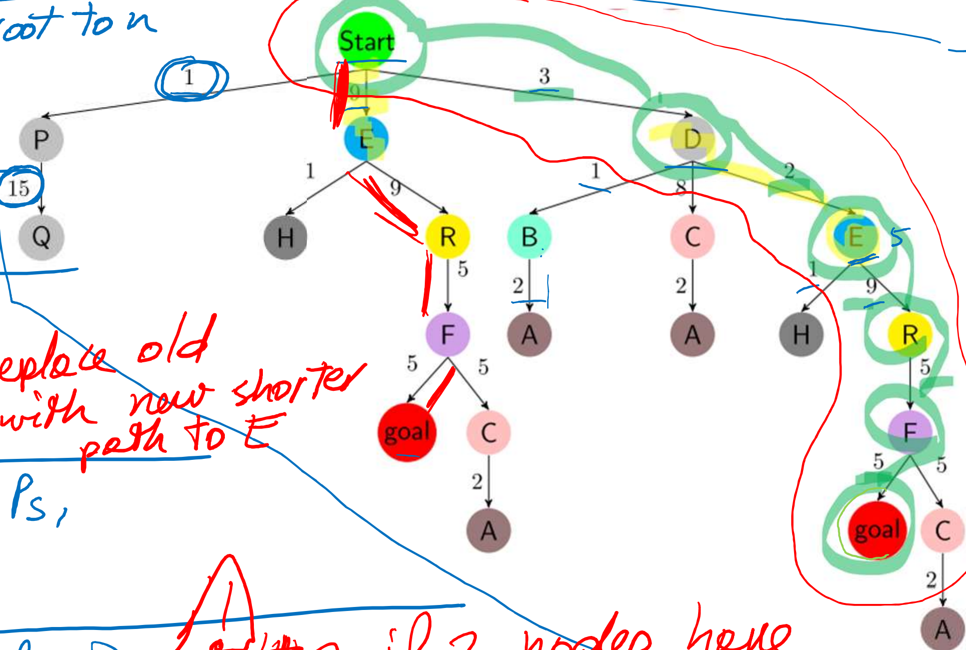
#2 if 2 nodes have the same cost in the open list ⇒ arbitrary choice

A_{B6} E_{D5} C_{D11} Q_{P16}
E_{D5} A_{B6} C_{D11} Q_{P16} | $S_{null\,0}$ P_{S1} D_{S3} B_{D4}

H_{E6} R_{E14} A_{B6} C_{D11} Q_{P16} | E_{D5}
H_{E6} A_{B6} C_{D11} R_{E14} Q_{P16}

I skipped the last steps

solution path : Goal F R E D S cost of 24



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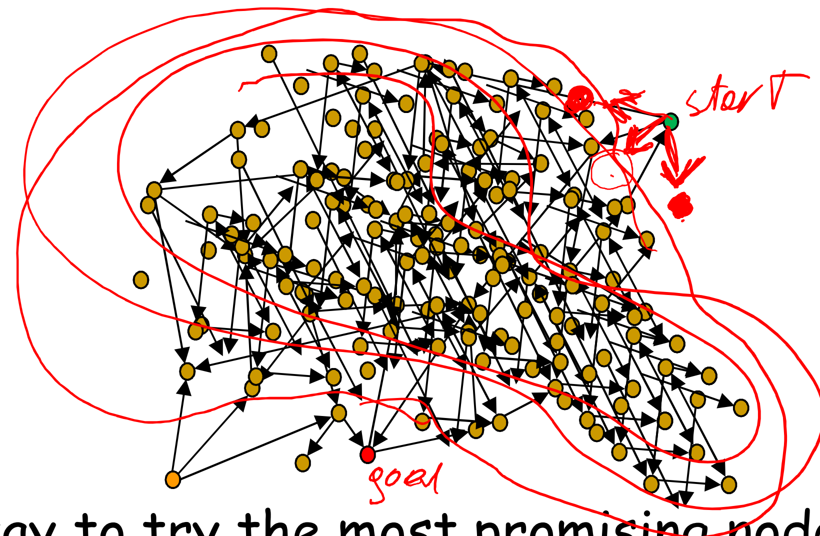
Problem with Uninformed Search

- inefficient for most AI problems, the state space is too large!
  - e.g. state space of all possible moves in chess = 10^{120}
  - 10^{75} = nb of molecules in the universe
  - 10^{26} = nb of nanoseconds since the "big bang"



- we need a way to try the most promising nodes first

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