TARC
TUNKU ABDUL RAHMAN UNIVERSITY COLLEGE
BEYOND EDUCATION

Chap 4 – Informed Search

"I climb all this way, and you tell me *THAT'S* the meaning of life?!"

Today's Aims

- Define and evaluate informed (heuristic) search
- Heuristic Search Techniques
  - Hill climbing
  - Best-first Search
  - A* Search

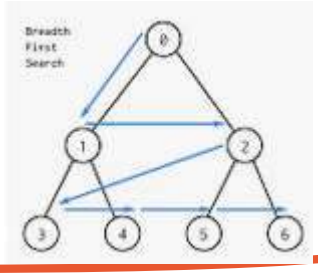
Recap (Chap 3)

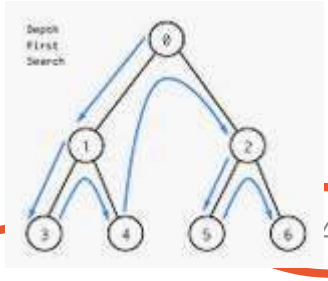
Search Strategies

- Uninformed Search/ Blind Search
  - BFS
  - DFS
  - Depth-limited search
  - IDS
  - Bidirectional search
- Informed Search/ Heuristic Search

BFS vs. DFS

	BFS	DFS
Completeness	Complete	Complete (as long as not trapped in endless loop)
Optimality	Optimal (shortest path)	Not optimal
Time Complexity	Depends on the location of the goal node.	
Space Complexity	Consume more memory	Consume less memory





Search Strategies

- Uninformed Search/ Blind Search
  - BFS
  - DFS
  - Depth-limited search
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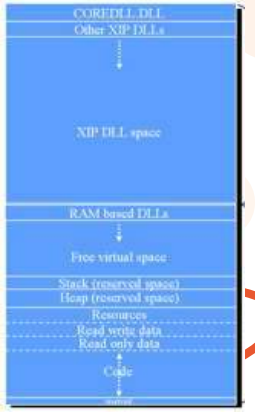
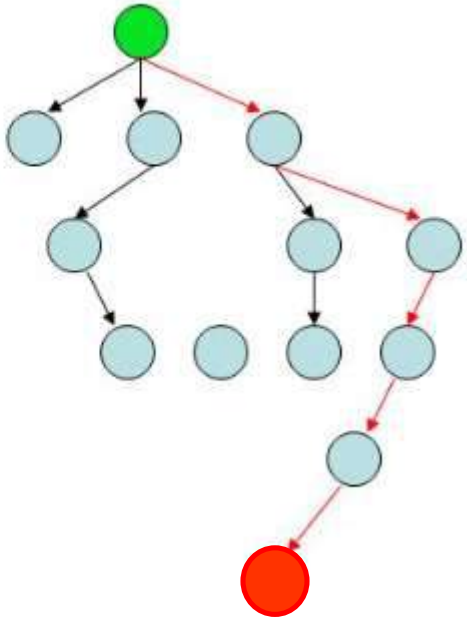
  - Bidirectional search
- Informed Search/ Heuristic Search



Heuristic

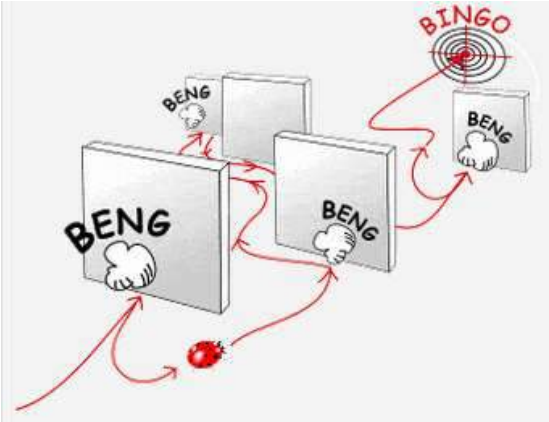
- A function that ranks alternatives at each branching step based on available information to decide which branch to follow [1].

Idea: be **smart** about what paths to try.



Notes

- Design a heuristic often based on experience or intuition.



- Heuristic is only an informed guess of the next step to be taken – seldom able to predict the exact behavior of the state space.
- Can lead to a suboptimal solution or fail

With heuristic

- The agent is informed which branch(es) in a state space that is(are) most likely to lead to an acceptable problem solution.

Heuristic Function

- The heuristic function, h(n) indicates how "close" a state *n* is to the goal.

Example

Let the heuristic function, h(n), is given as follows:

h(n) = estimated distance of state *n* from goal

= number of tiles at the right place.

* h(n) determines the heuristic cost of a state

Initial:

h = 4

2	8	3
1	6	4
7		5

Final:

h = 8

1	2	3
8		4
7	6	5

Goal

Hill Climbing

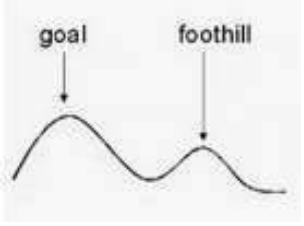
- The simplest way in heuristic search
- 2 types:
  - Simple Hill Climbing
  - Steepest Ascent Hill Climbing

Limitations of Hill Climbing

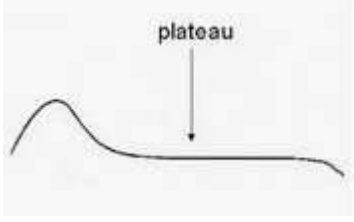
- It is less combinatorially explosive as it searches locally rather than globally;
- possibly very inefficient and ineffective .

Limitations of Hill Climbing

- Hill climbing may encounter **local maximum**, which are
  1. Foothills



  2. Plateau



  3. Ridges

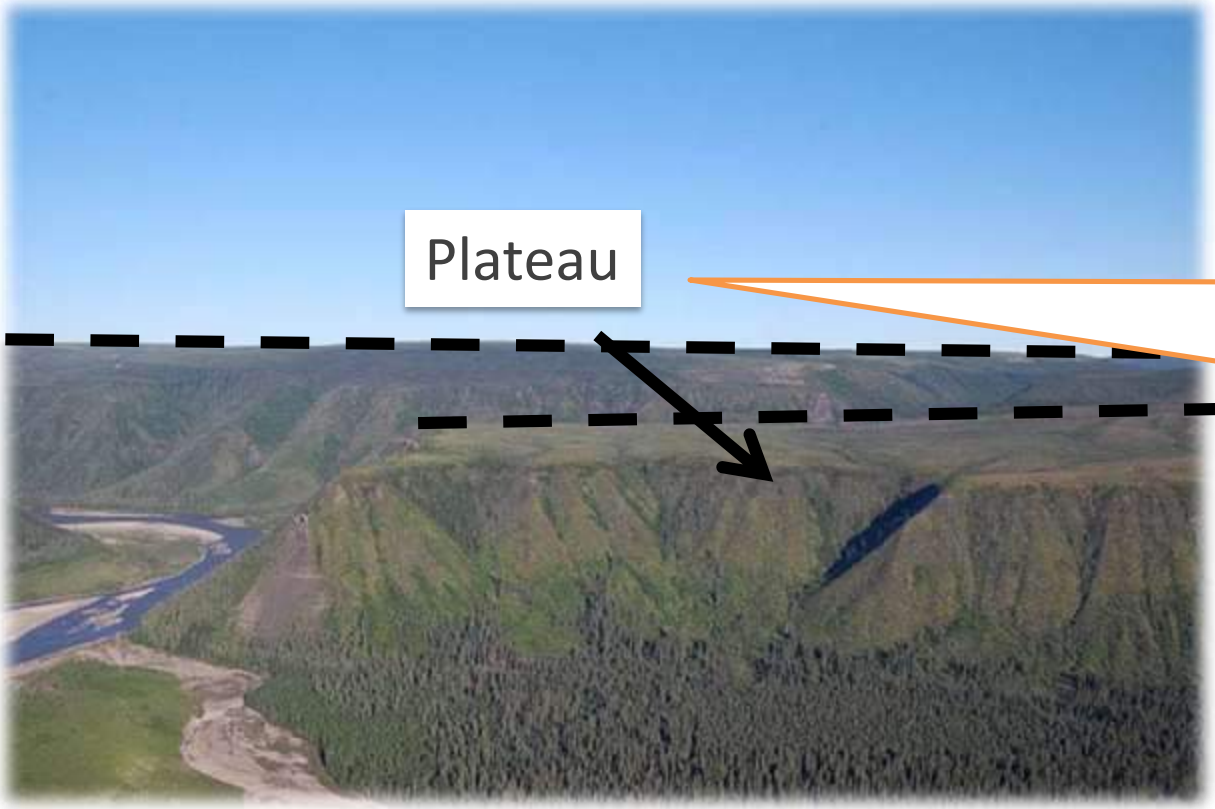
Foothill

Foothill - a state that has no better move.

A simple hill climber will never find a solution though one exists.

Plateau

An area of state space where the heuristic values are equal.

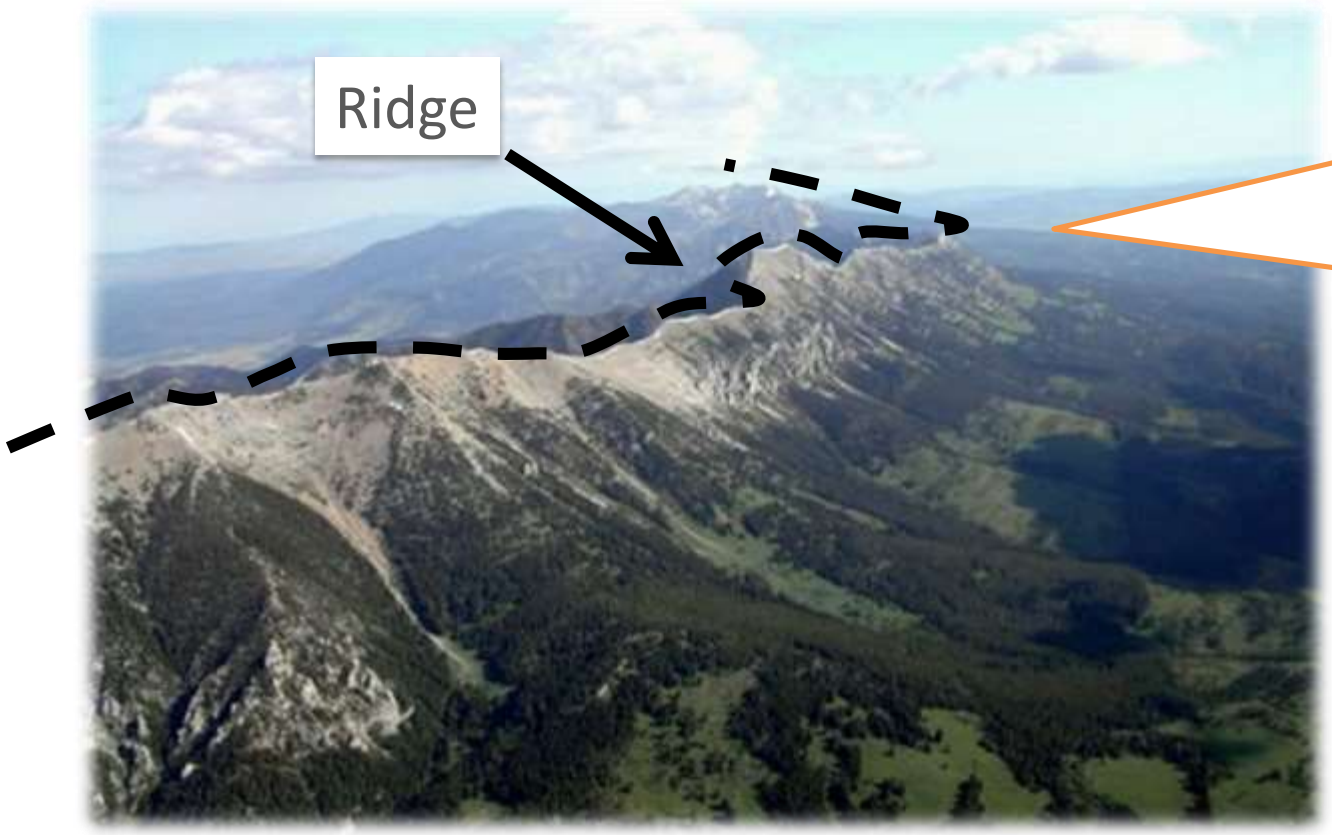


A hill climber will not know which direction to follow

To proceed, the search algorithm may conduct a random walk.

Ridge

An area of state space bordered by lower values in an descending search (or higher values in ascending search)



the ridge may slope very slowly toward the peak making it a long route.

Simple Hill Climbing

ALGORITHM

1. Set initial state to current
2. Loop on the following until goal is found or no more operators available
   - Select an operator and apply it to create a new state
   - Evaluate new state
   - If new state is better than current state, perform operator making new state the current state
3. Once loop is exited, either we have found the goal or return fail

Example

Let the heuristic function, h(n), is given as follows:

h(n) = estimated distance of state *n* from goal

= number of tiles at the right place.

* h(n) determines the heuristic cost of a state

Initial:

h = 4

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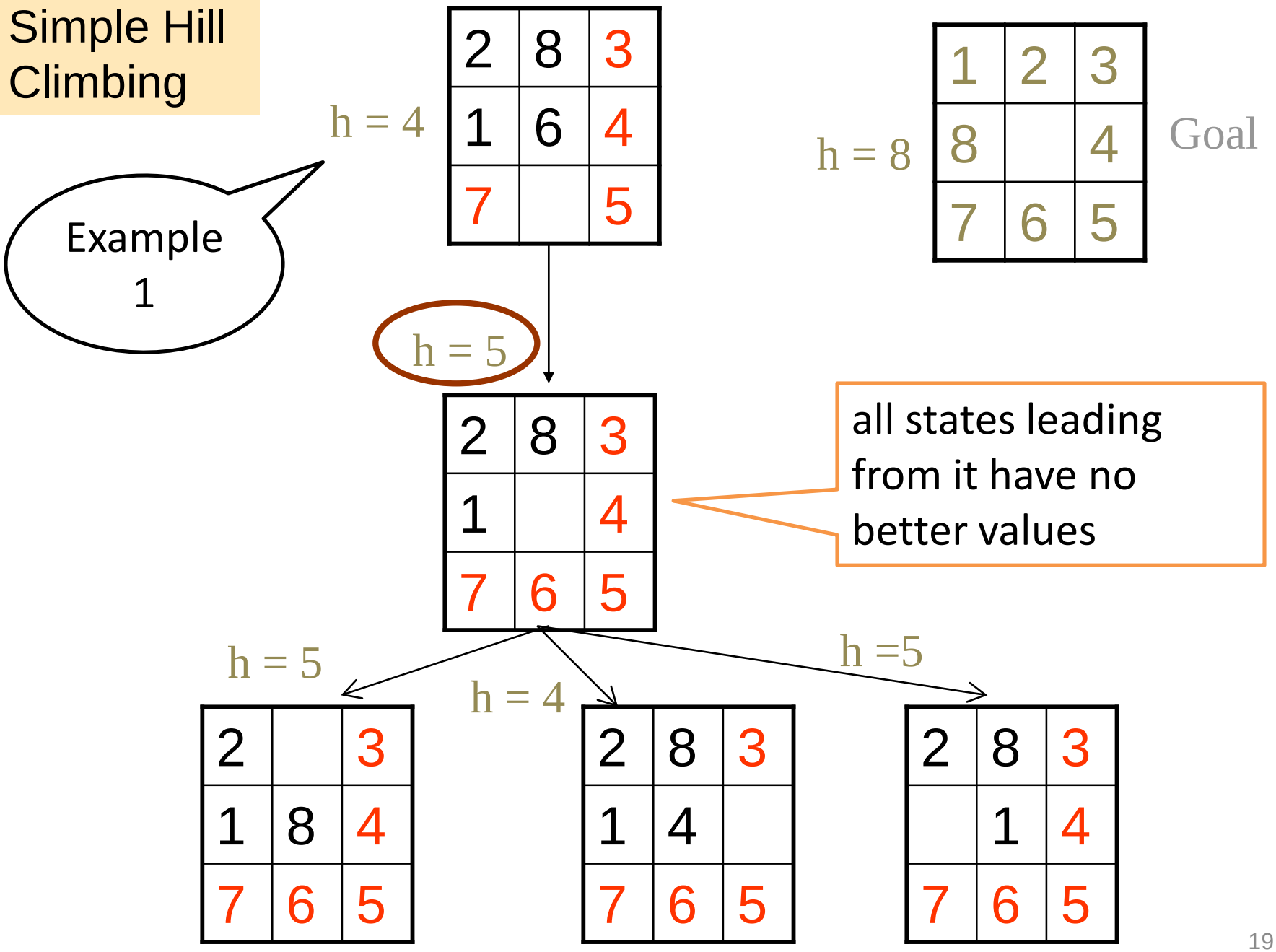
Final:

h = 8

1	2	3
8		4
7	6	5

Goal

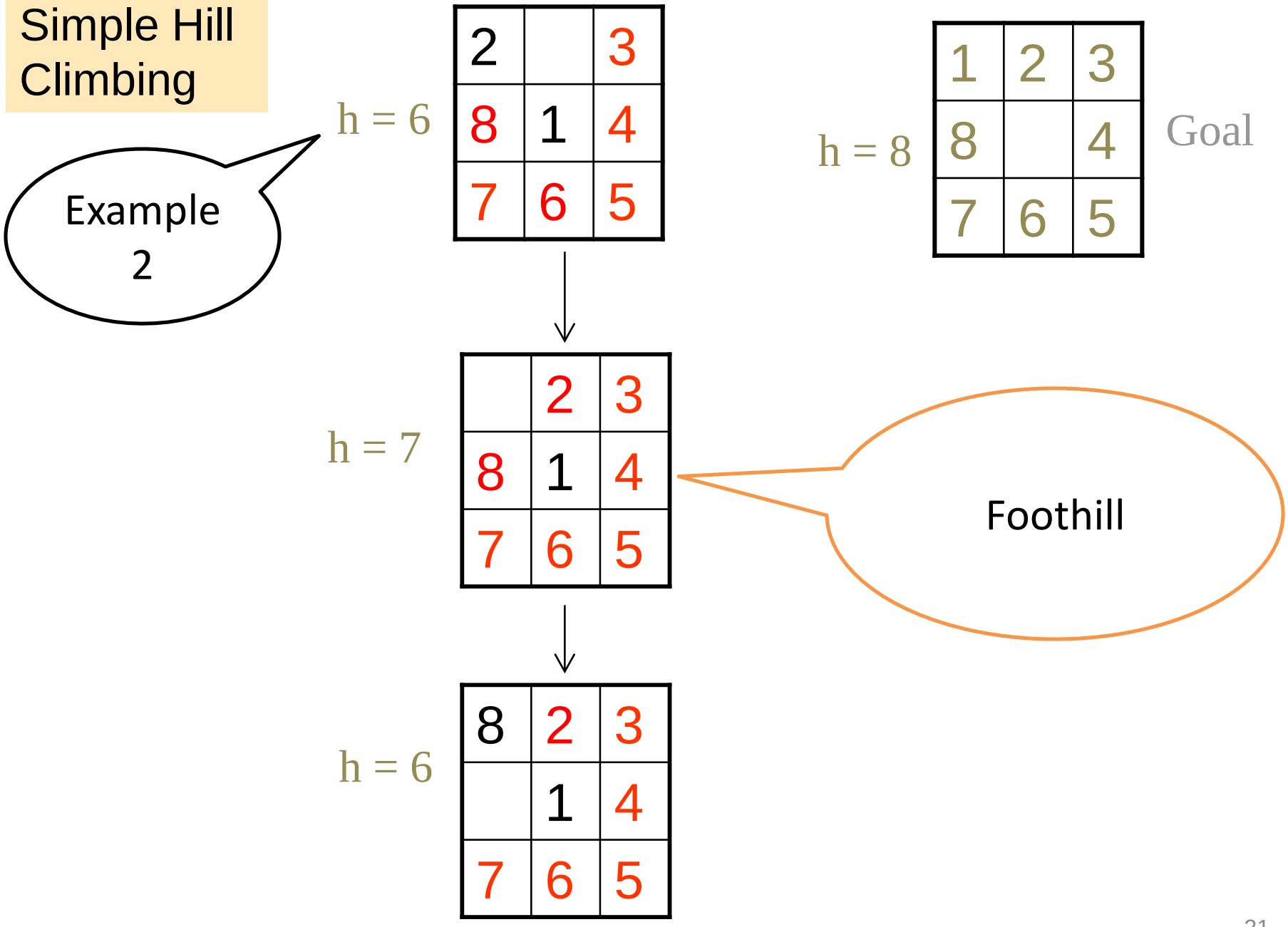
Simple Hill Climbing



Ops! We're stuck!

- Simple hill climbing has faced a dead end.
- The child nodes are worse than the parent node.
- This problem is known as **foothill**.

Simple Hill Climbing

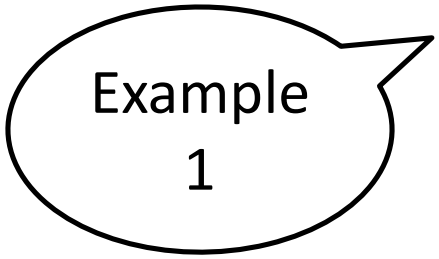


Steepest Ascend Hill Climbing

- Here, we attempt to improve on the previous Hill Climbing algorithm
  - Given initial state perform the following

1. Set initial state to current
2. Loop on the following until goal is found or a complete iteration occurs without change to current state
   - Generate all successor states to current state
   - Evaluate all successor states using heuristic
   - Select the successor state that yields the highest heuristic value and perform that operator

SAHC



h = 2

2	6	3
1	8	4
7		5

h = 8

1	2	3
4	5	6
7	8	

Goal

h = 3

2	6	3
1		4
7	8	5

h = 1

2	6	3
1	8	4
	7	5

h = 2

2	6	3
1	8	4
7	5	

2		3
1	6	4
7	8	5

h = 3

2	6	3
1	4	
7	8	5

h = 3

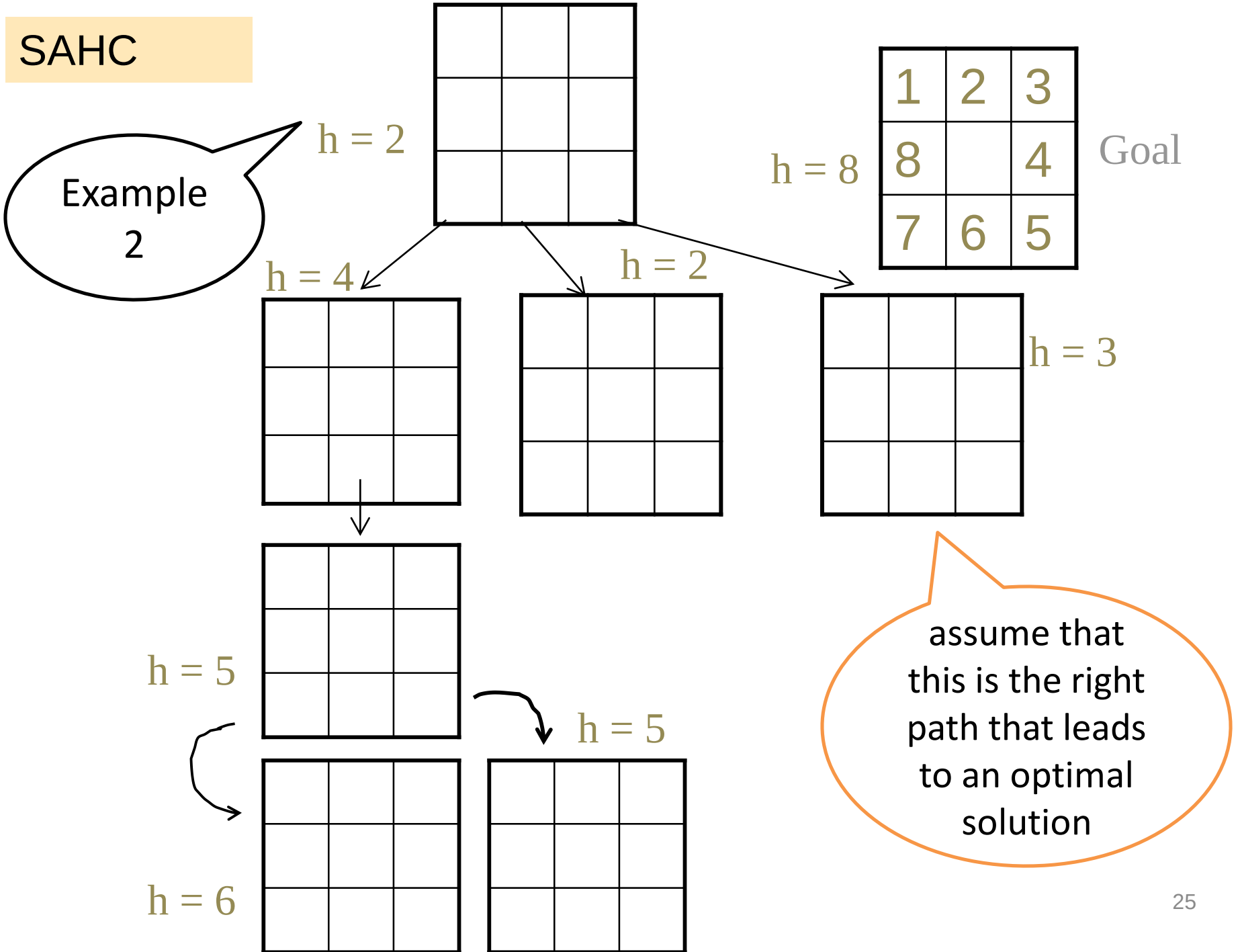
2	6	3
	1	4
7	8	5

h = 3

Ops! We're stuck again!

- SAHC has also faced a dead end.
- All heuristic costs are the same.
- This problem is known as **plateau**.

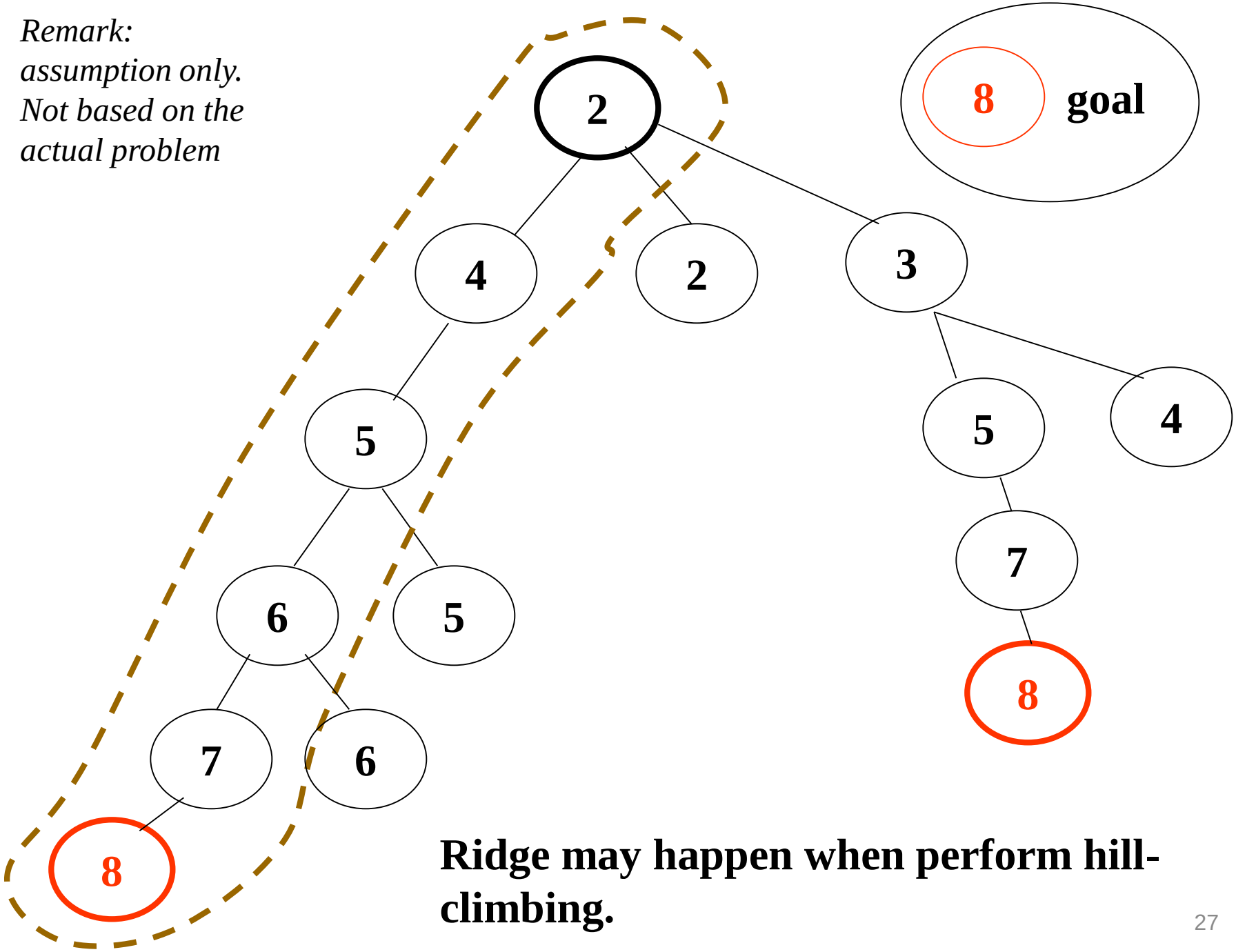
SAHC


Example 2
h = 2
h = 8
1 2 3
8 4
7 6 5
Goal
h = 4
h = 2
h = 3
h = 5
h = 5
h = 6
assume that this is the right path that leads to an optimal solution

Ops! It took the wrong path!

- The actual path that the search took in Example 2 leads to a sub-optimal solution (longer path).
- The problem is known as **ridge**.

Remark:
assumption only.
Not based on the
actual problem



Ridge may happen when perform hill-climbing.

Designing a Heuristic Function

- **Local Heuristic**
  - less combinatorially explosive (less complex)
  - possibly very inefficient and ineffective
- **Global Heuristic**
- - Consider the global information
  - possibly more efficient than local heuristic

There is NO GUARANTEE that a heuristic can always produce a solution/optimal solution

Heuristic Search

Simple Hill Climbing

vs

Steepest Ascent Hill Climbing

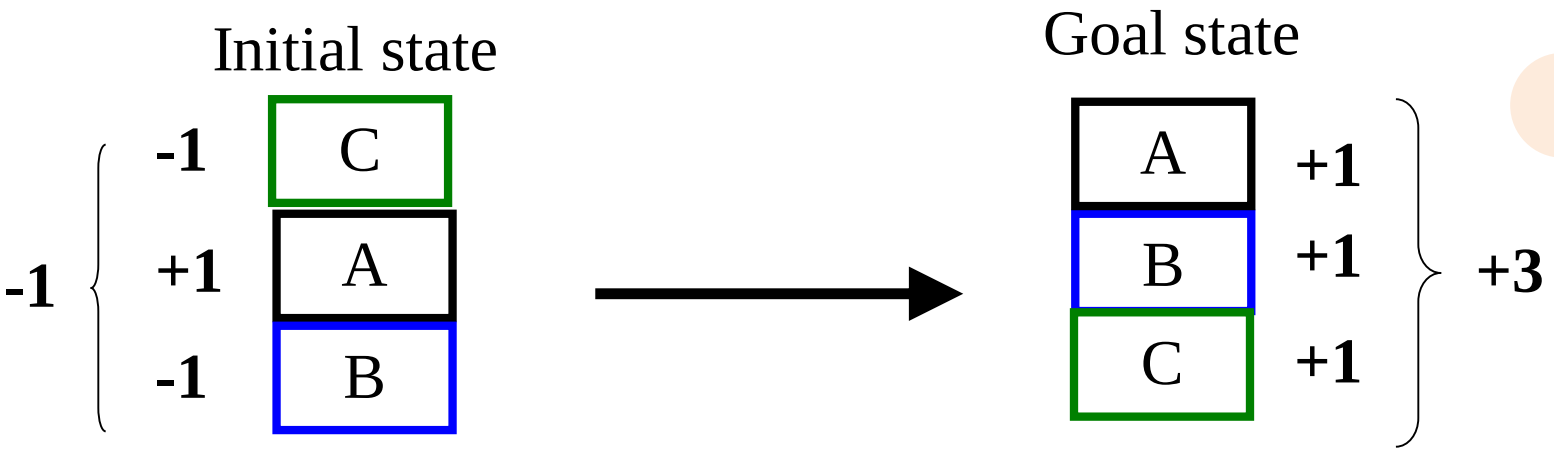
- Similarity?

❖ Global information might be encoded in heuristic functions.

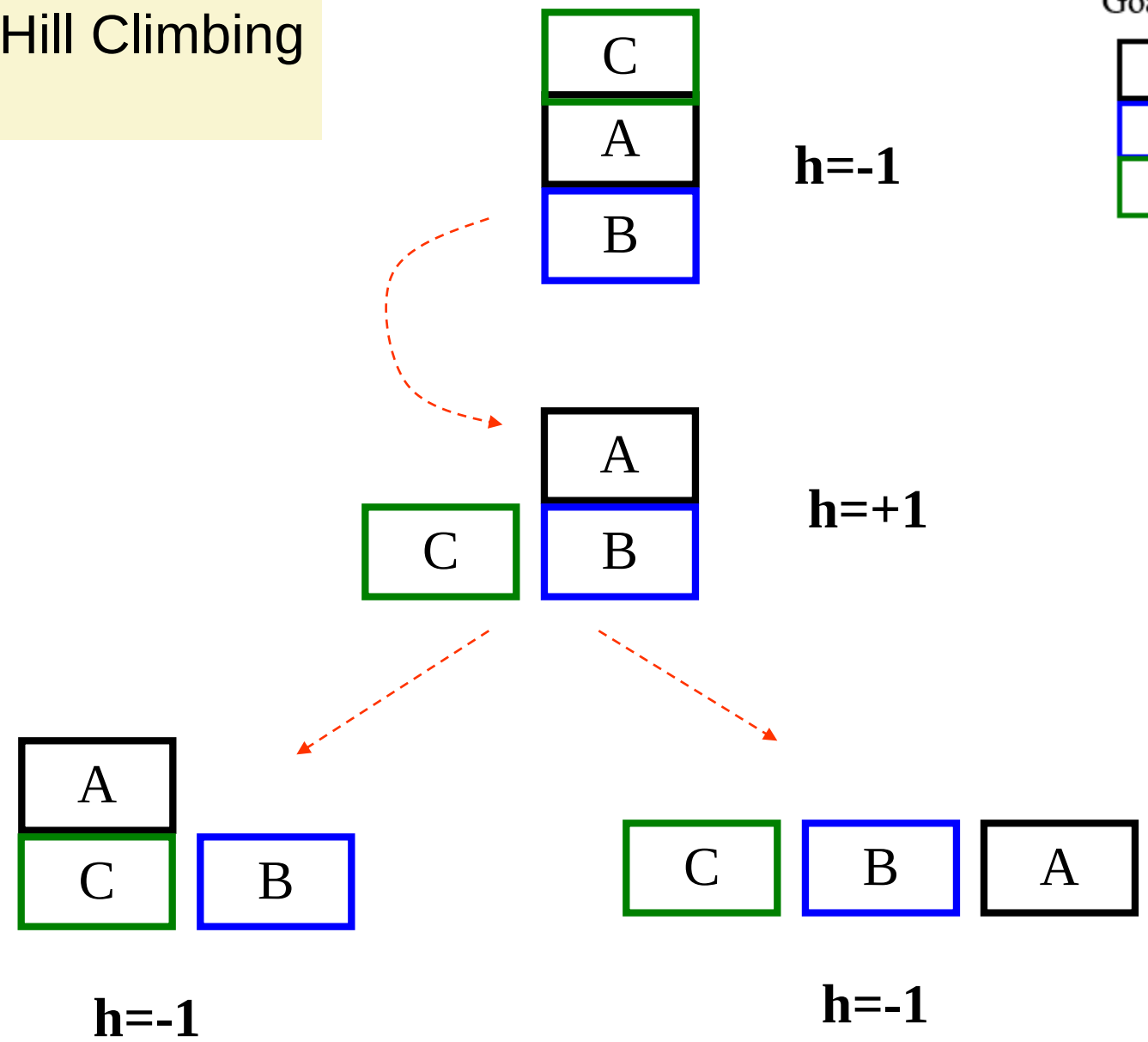
Local Heuristic

- **Heuristic**: IF the block is rest on the right place, Add 1. ELSE Minus 1.

: Easy to design ☺



Simple Hill Climbing SAHC



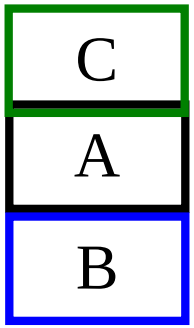
Ops! We are stuck!

- 👎: It is proven local heuristic is ineffective and inefficient ☹

Global Heuristic

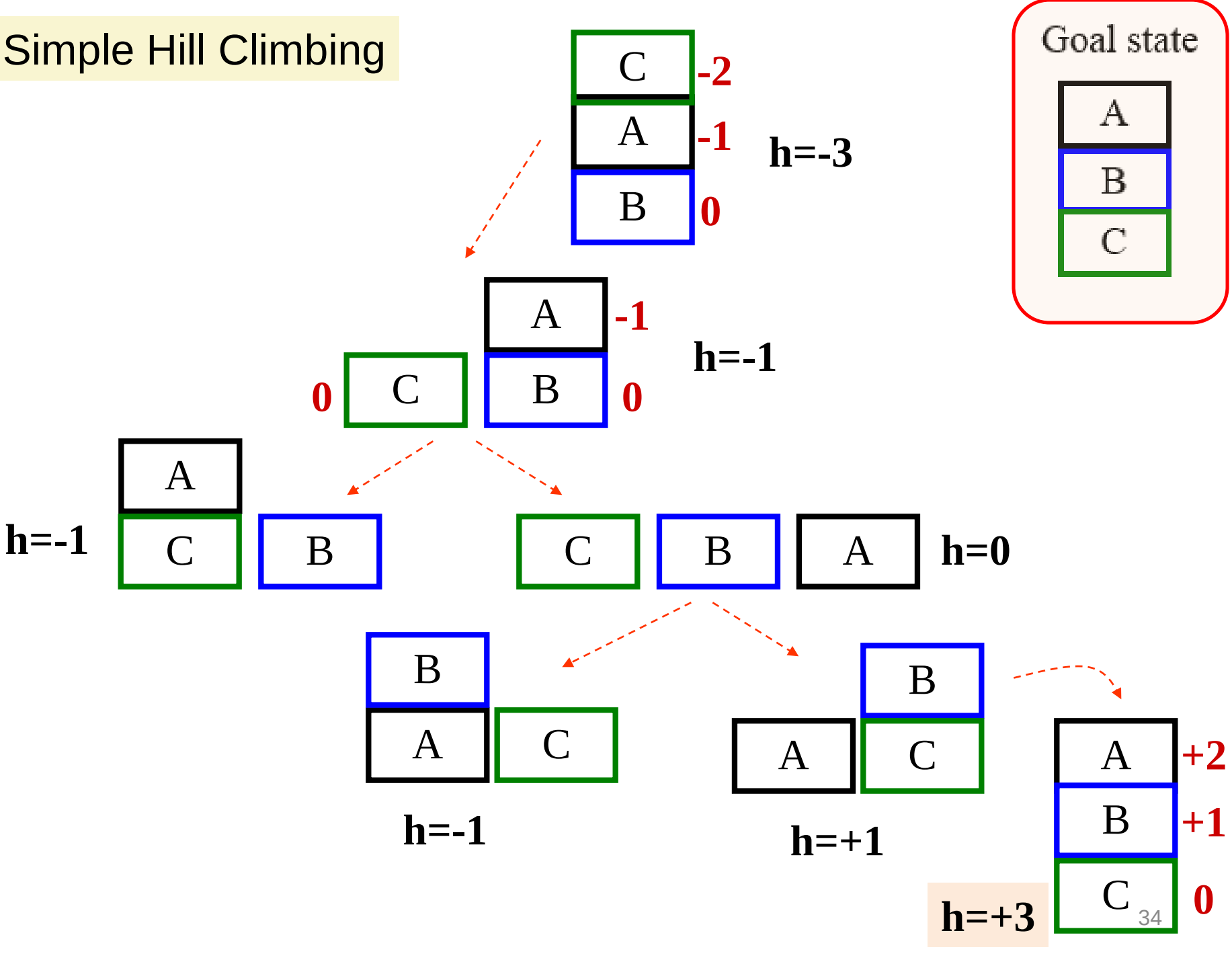
- **Heuristic:**

1. For each block that has correct support structure, + 1 for every block in the support structure.
2. For each block that has an incorrect support structure, - 1 for each block in the each block in the existing structure.

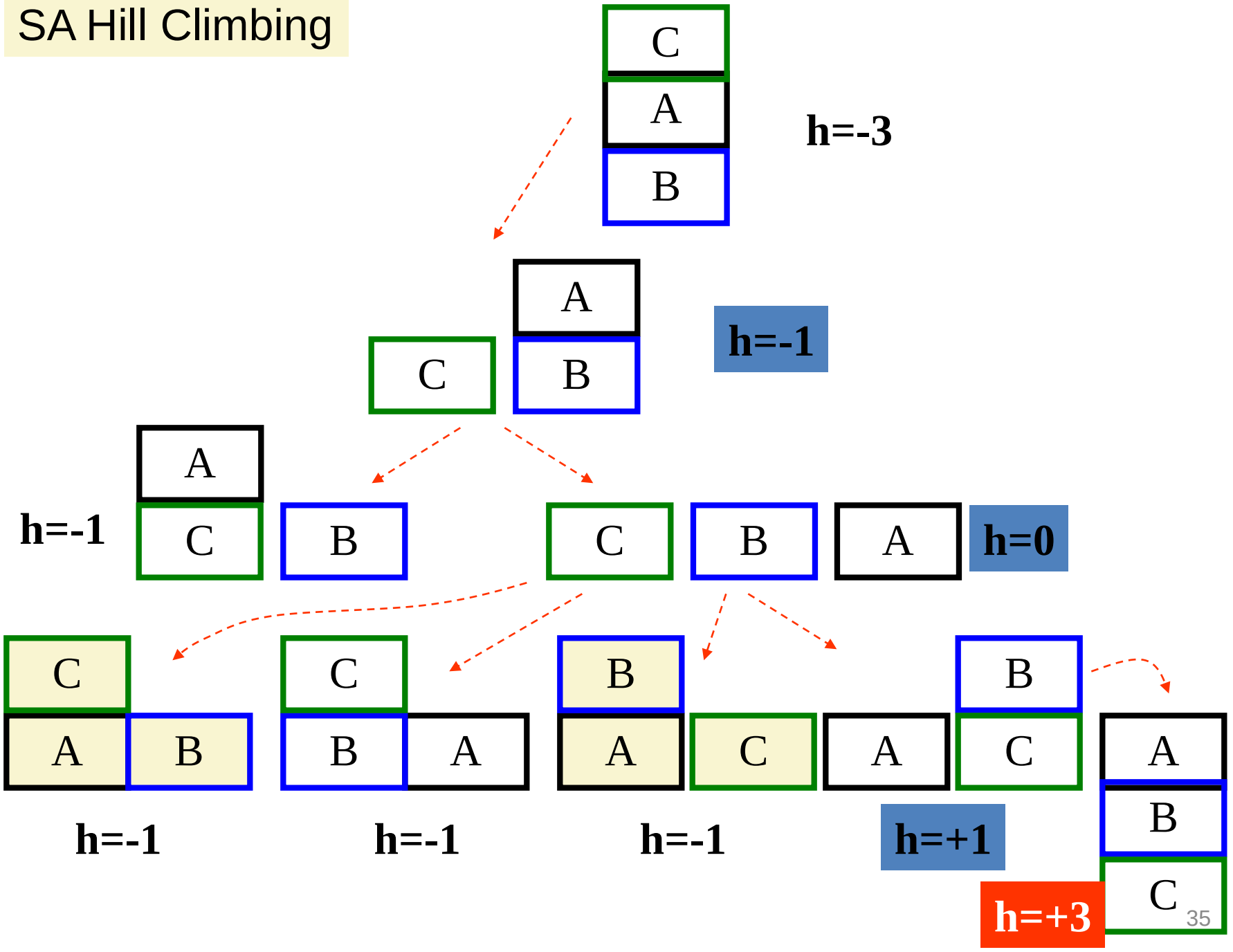


- The support for C is A & B
- The support for A is B
- The support for B is table, but the table is not a block

Simple Hill Climbing



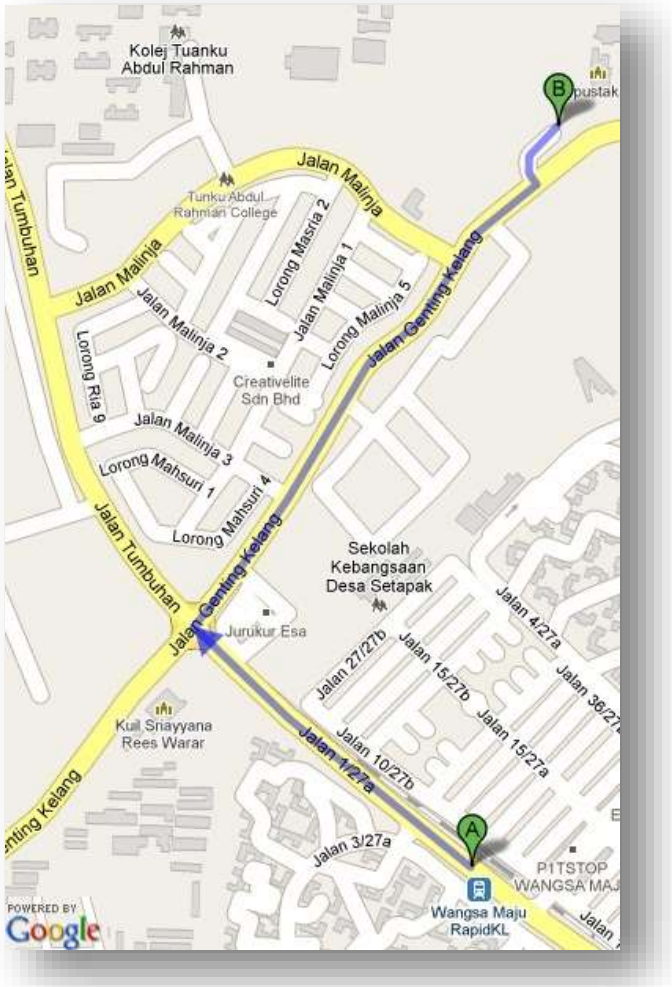
SA Hill Climbing



Conclusion

- Hill climbing is not always effective
- Heuristic function not always perfect
- Modify the heuristic function
- Inefficient in a large, rough problem space

Best First Search



Recall

- Depth-first search
  - without traverse all the branches.
- Breadth-first search
  - Not trapped into a dead-end path.

Best-first search =

depth-first search **+** breadth-first search

Best First Search

- More flexible
- Use priority queue
- Heuristic is used (to estimate the promising state/path)

Best-first Search Algorithm

- Set *Open* := [Start] and *closed* := [ ]
- Loop until open := [ ]
  - Remove the LEFTMOST node *X* from *open*
  - If *X* = *goal* then return the path from *Start* to *X*
  - Else generate children of *X*
  - For each child of *X*
    - If the child is on *open* or *closed*
      - Assign the child its heuristic value
      - Add the child to open
    - Else if the child is on open
      - If the child was reached by a shorter path
        - Give the child a state on open the shorter path

…CONT NEXT PAGE

Best-first Search Algorithm -CONT

- Else if the child is already on closed
  - If the child was reached by a shorter path
    - Remove the state from closed
    - Add the child to open
- Put X on closed
- Sort states on open by heuristic merit (best leftmost)

Return fail

After loop till open = [ ]

Back to exercise

heuristic

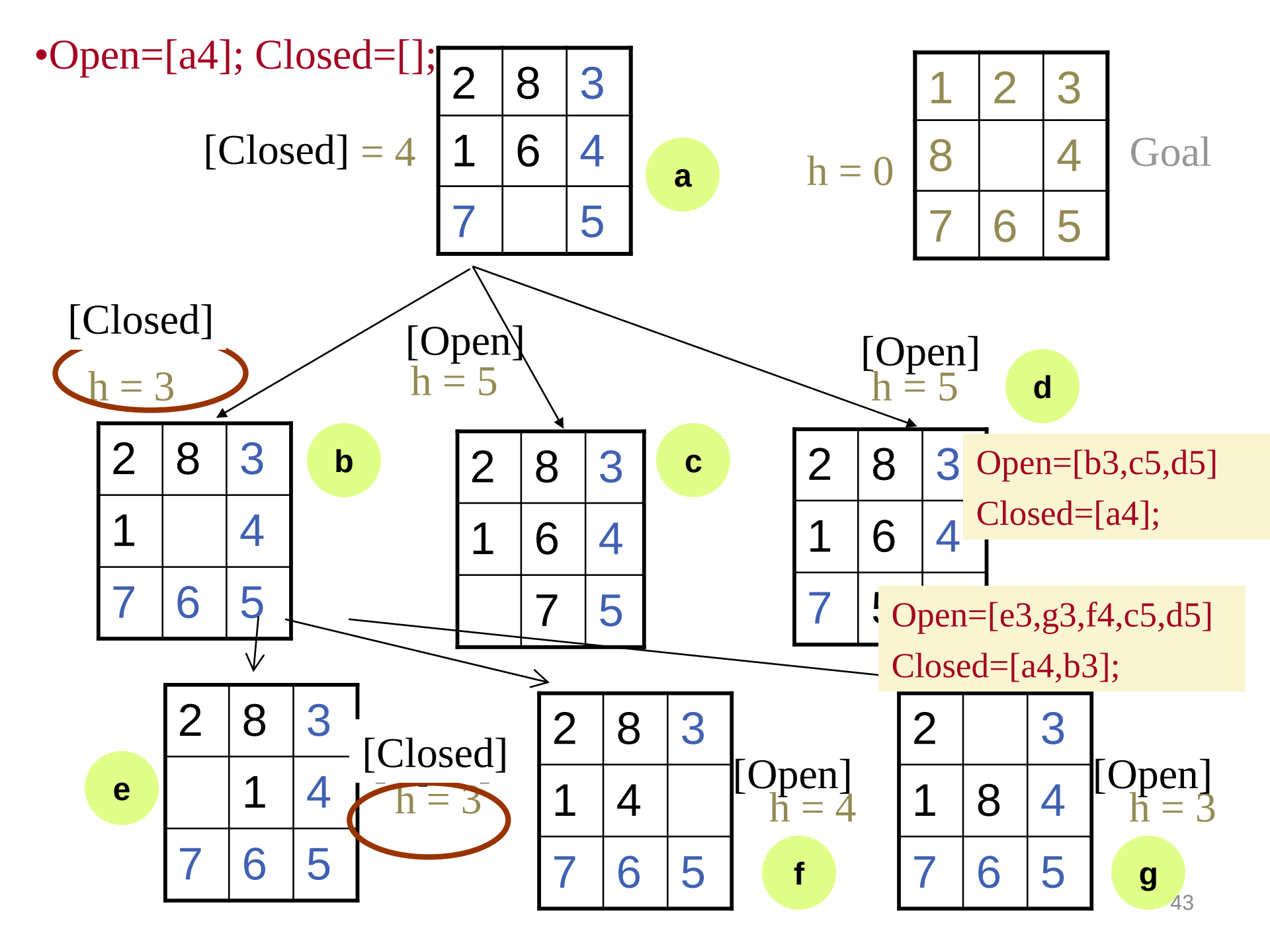
- Let:
- h(n) = estimated distance of state n from goal
- = number of tiles at the wrong place.
- * h(n) = heuristic cost
- Initial:

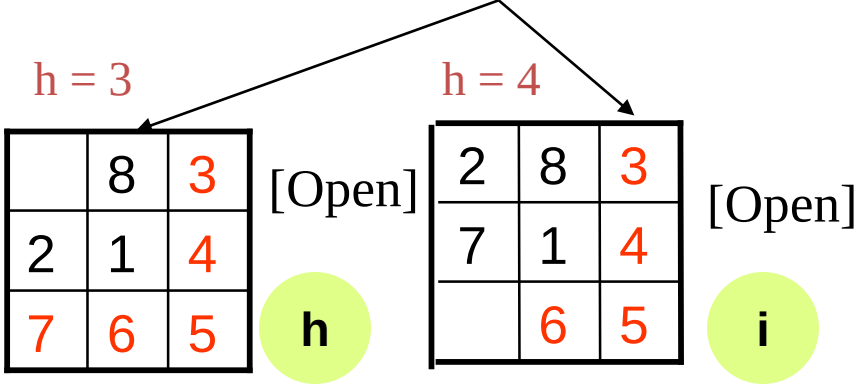
2	8	3
1	6	4
7		5

Final:

1	2	3
8		4
7	6	5

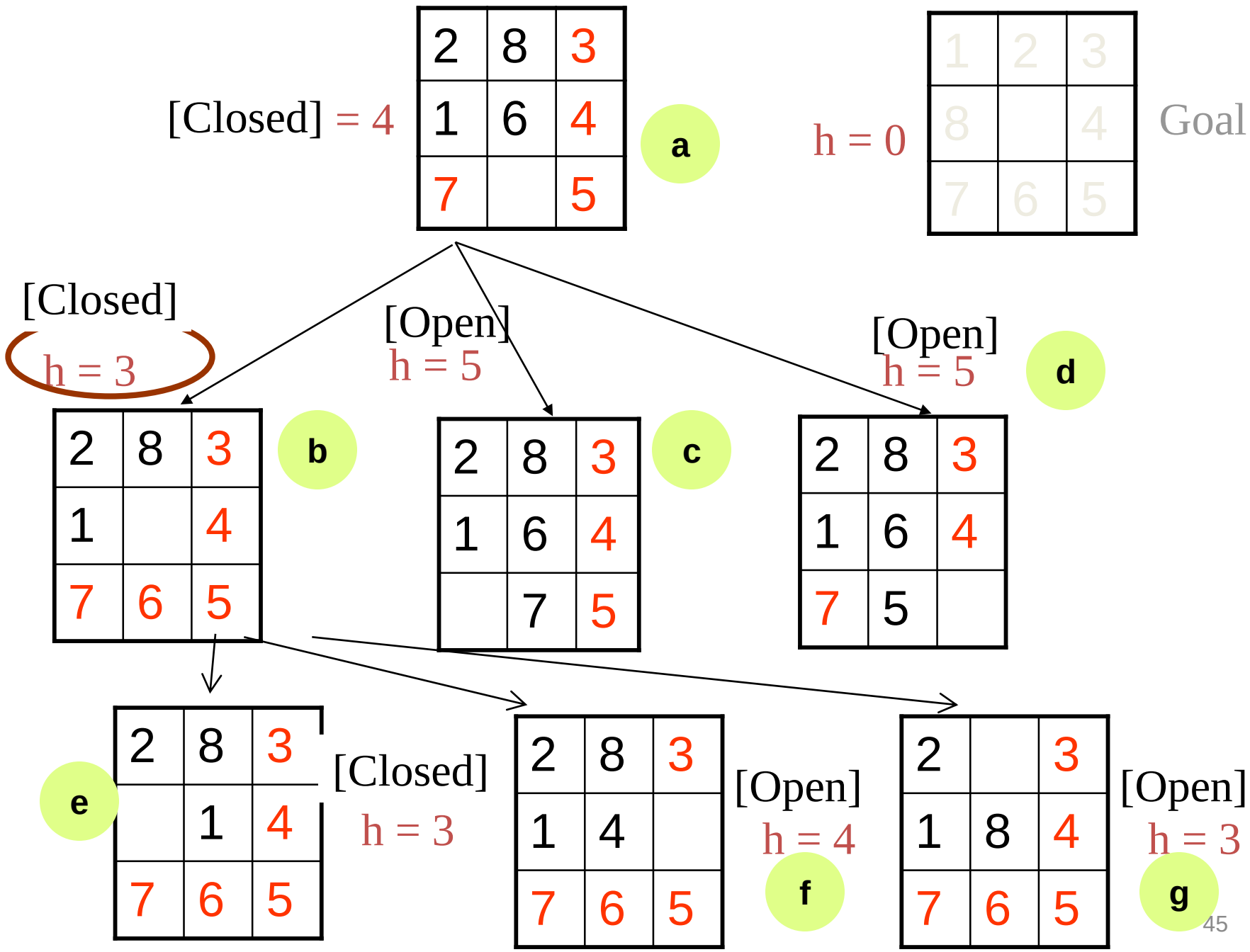
•Open=[a4]; Closed=[];

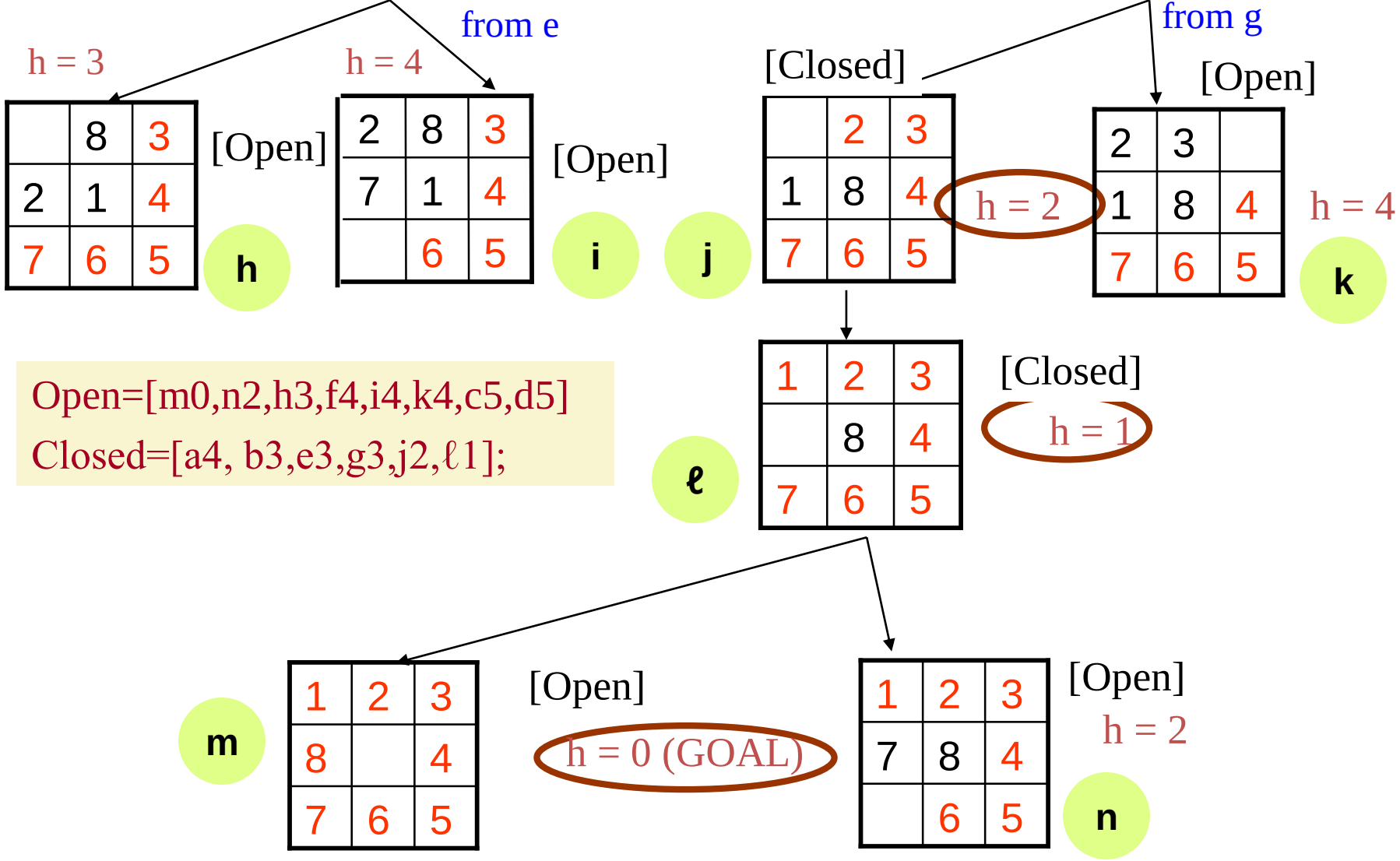




Open=[g3,h3,f4,i4,c5,d5]

Closed=[a4,b3,e3]

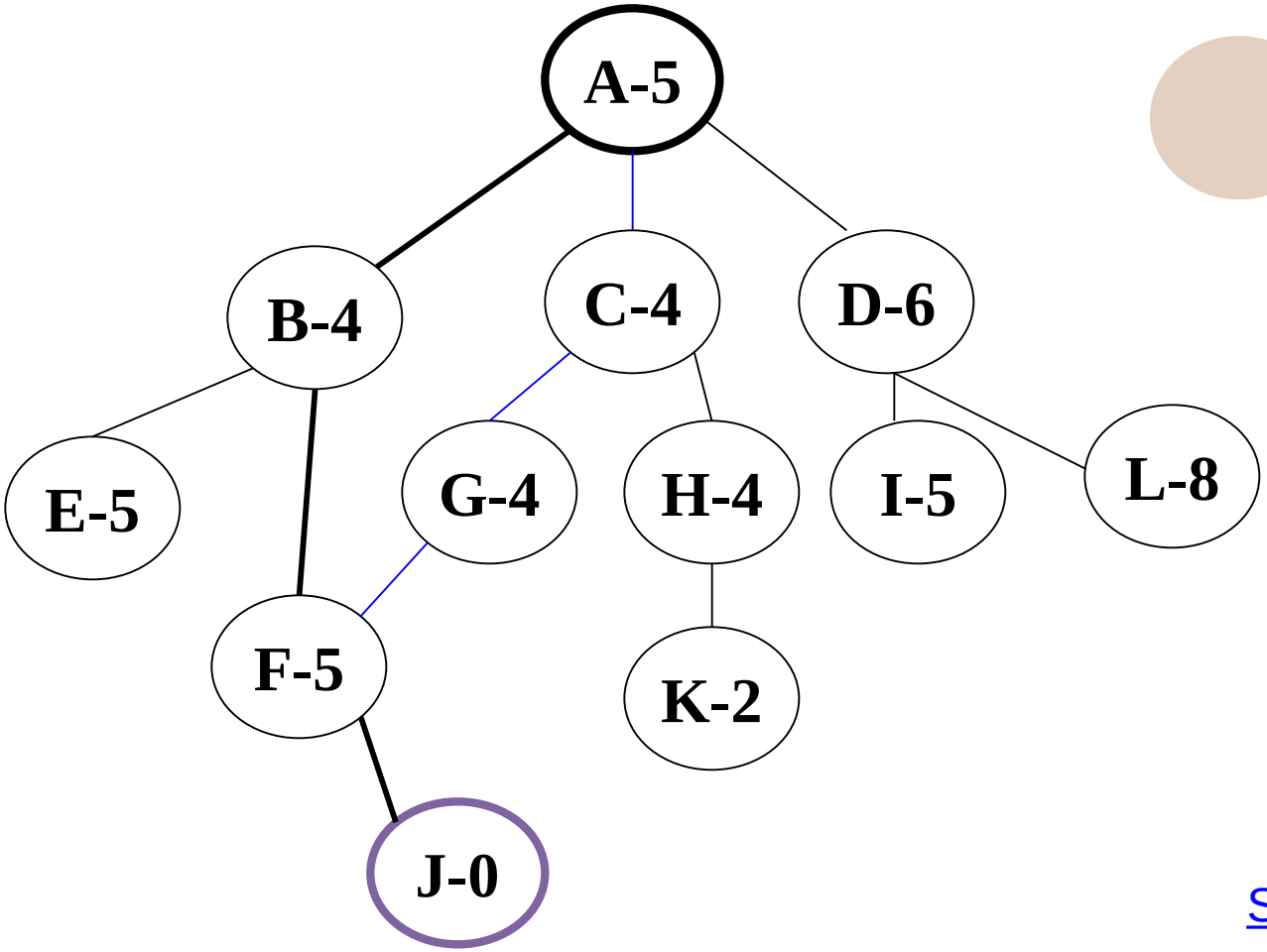

[Closed] = 4
2 8 3
1 6 4
7 5
a
h = 0
1 2 3
8 4
7 6 5
Goal
[Closed]
h = 3
[Open]
h = 5
[Open]
h = 5
d
2 8 3
1 4
7 6 5
b
2 8 3
1 6 4
7 5
c
2 8 3
1 6 4
7 5
e
2 8 3
1 4
7 6 5
[Closed]
h = 3
2 8 3
1 4
7 6 5
[Open]
h = 4
f
2 3
1 8 4
7 6 5
[Open]
h = 3
g


from e
h = 3
h = 4
[Open]
[Open]
h
i
[Closed]
from g
[Open]
h = 2
h = 4
j
k
Open=[m0,n2,h3,f4,i4,k4,c5,d5]
Closed=[a4, b3,e3,g3,j2,ℓ1];
ℓ
[Closed]
h = 1
m
[Open]
h = 0 (GOAL)
[Open]
h = 2
n

Open & Closed List

- Open=[a4]; Closed=[];
- Open=[b3,c5,d5]; Closed=[a4];
- Open=[e3,g3,f4,c5,d5]; Closed=[a4,b3];
- Open=[g3,h3,f4,i4,c5,d5];Closed=[a4,b3,e3];
- Open=[j2,h3,f4,i4,k4,c5,d5]; Closed=[a4,b3,e3,g3];
- Open=[ℓ1,h3,f4,i4,k4,c5,d5];
  Closed=[a4, b3,e3,g3,j2];
- Open=[m0,n2,h3,f4,i4,k4,c5,d5];
  Closed=[a4, b3,e3,g3,j2,ℓ1];
- Evaluate m0; the solution is found; return path = a->b->g->j->ℓ->m

Exercise



See algorithm

Trace

- Open=[a5]; Closed=[];
- Eval A-5: Open=[b4,c4,d6]; Closed=[a5];
- Eval B-4: Open=[c4,e5,f5,d6]; Closed=[b4,a5];
- Eval C-4: Open=[g4,h4,e5,f5,d6];Closed=[c4,b4,a5];
- Eval G-4: Open=[h4,e5,f5*,d6]; Closed=[g4,c4,b4,a5];
- Eval H-4: Open=[k2, e5,f5*,d6]; Closed=[h4, g4,c4,b4,a5];
- Eval K-2: Open=[e5,f5*,d6]; Closed=[k2,h4, g4,c4,b4,a5];
- Eval E-5: Open=[f5*,d6]; Closed=[e5,k2,h4, g4,c4,b4,a5];
- Eval F-5: Open=[j0,d6]; Closed=[f5*,e5,k2,h4, g4,c4,b4,a5];
- Eval j-0: Goal is found! Return path = a->b->f->j
- * f5 was reached by B-4

A* Search (Luger, pg 139)

Heuristic Function:

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

  where:

  g(n) = distance n from the start state and

  g(start state) = 0

  h(n) = number of tiles out of place, hence

  h(goal) = 0 $(h_1(n))$ **OR**

  h(n) = the sum of the Manhattan distances of the tiles from their goal positions, hence
  h(goal) = 0 $(h_2(n))$

look for minimum(f(n)) and h(n) = 0

g(n) = 0

[Closed] f(a) = 4

2	8	3
1	6	4
7		5

h(goal) = 0

1	2	3
8		4
7	6	5

Goal

[Closed]
f(b) = 4

[Open]
f(c) = 6

[Open]
f(d) = 6

g(n)=1

2	8	3
1		4
7	6	5

2	8	3
1	6	4
	7	5

2	8	3
1	6	4
7	5	

g(n)=2

2	8	3
	1	4
7	6	5

[Closed]
f(e)=5

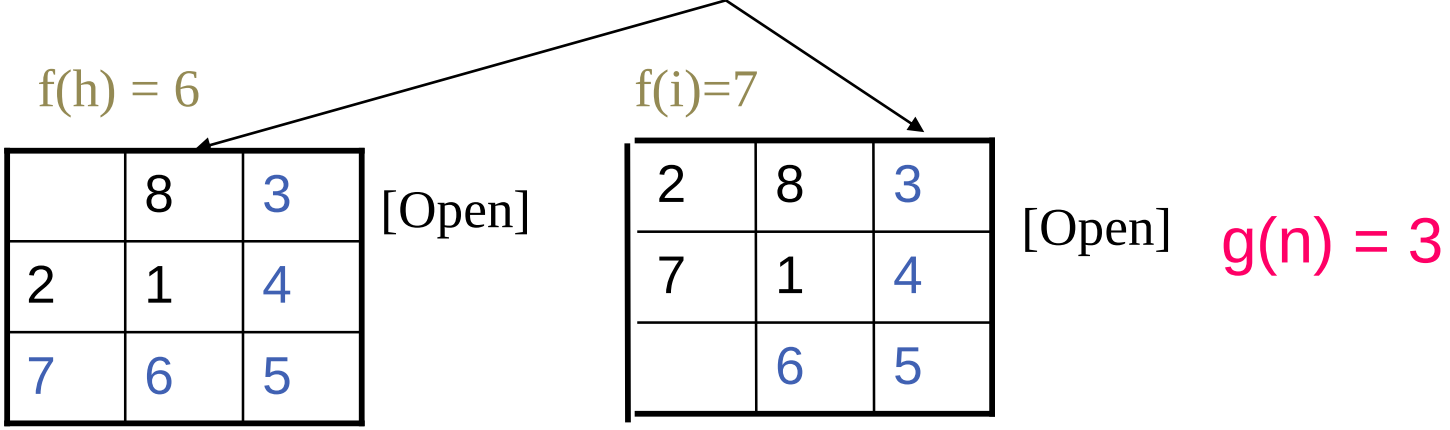
2	8	3
1	4	
7	6	5

[Open]
f(f)=6

2		3
1	8	4
7	6	5

[Open]
f(g)=5

51



Open=[g5,c6,d6,f6,h6, i7]
Closed=[e5,b4,a4];

The same process will be iterated until the goal is found

g(n) = 0

f(a) = 5

2	8	3
1	6	4
7		5

h(goal) = 0

1	2	3
8		4
7	6	5

Goal

f(b) = 5

2	8	3
1		4
7	6	5

f(c) = 7

2	8	3
1	6	4
	7	5

f(d) = 7

2	8	3
1	6	4
7	5	

g(n)=1

The same process will be iterated until the goal is found

g(n)=2

2	8	3
	1	4
7	6	5

f(e)=7

2	8	3
1	4	
7	6	5

f(f)=7

2		3
1	8	4
7	6	5

f(g)=5

Differences between SAHC and BFS

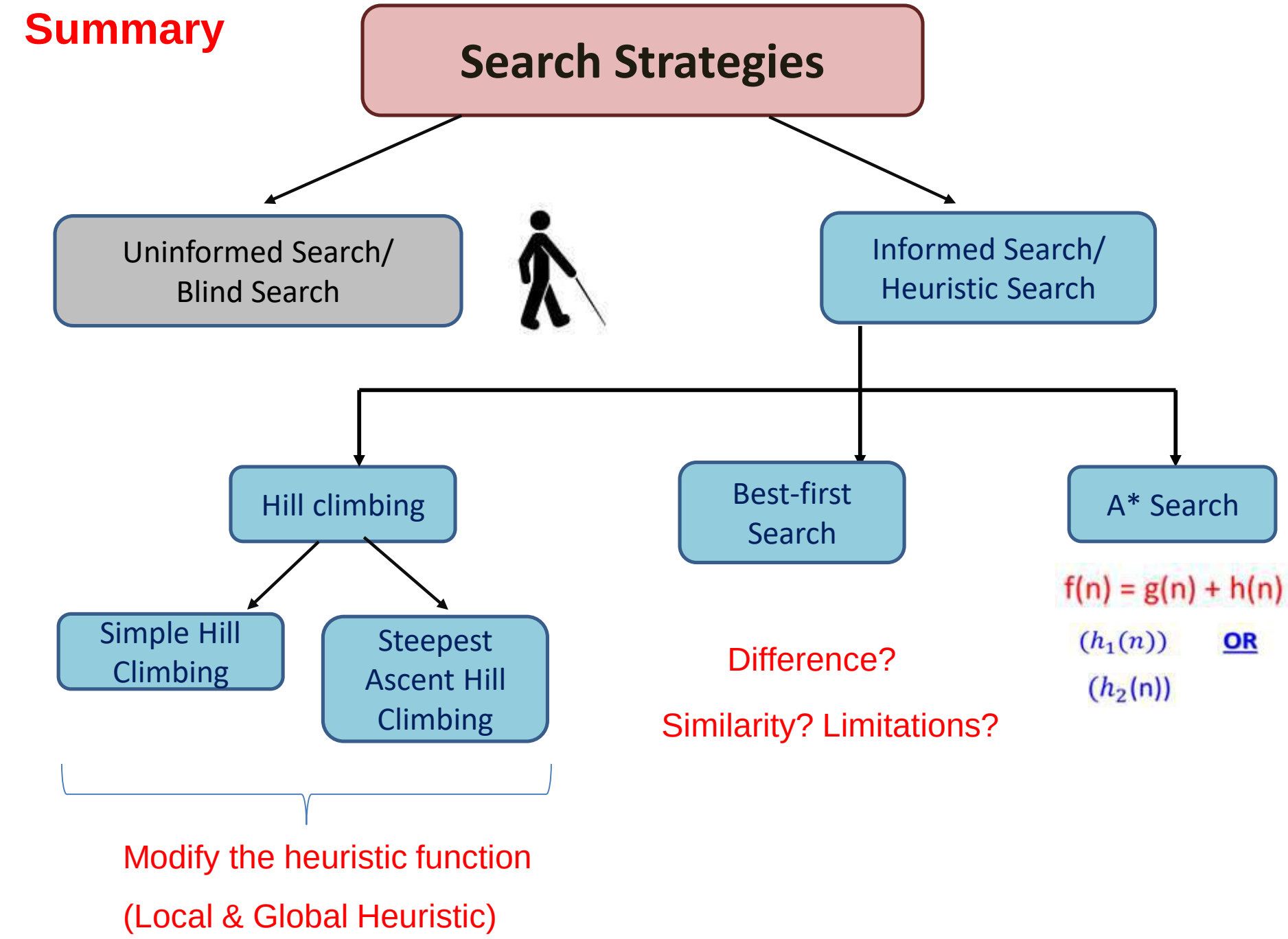
SA Hill-climbing

- one move is selected and all others are rejected, which will not be reconsidered.
- will quit if there is no better successor /children state than the current state.

Best-first search

- one move is selected, but others are still kept around so that they can be revisited later.
- will try on other nodes which initially was less promising

Summary


Search Strategies
Uninformed Search/ Blind Search
Informed Search/ Heuristic Search
Hill climbing
Best-first Search
A* Search
Simple Hill Climbing
Steepest Ascent Hill Climbing
f(n) = g(n) + h(n)
$(h_1(n))$
OR
$(h_2(n))$
Difference?
Similarity? Limitations?
Modify the heuristic function
(Local & Global Heuristic)

Next Week

Knowledge representation