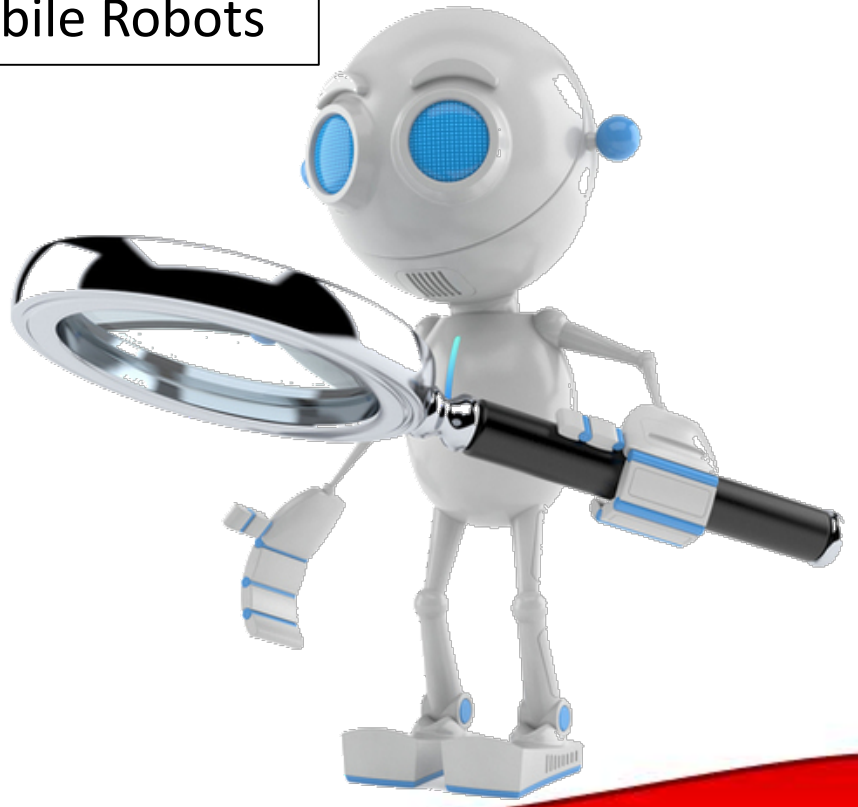
Algorithms and Path Planning

Topics
- Simple Search
- Depth First Search
- Breadth First Search
- Dijkstra's Search
- Greedy Search
- A* Search

Classes of interest
- ECE2400: Computer Systems Programming
- CS4700: Foundations of Artificial Intelligence
- CS4701: Practicum of Artificial Intelligence
- CS3758/MAE4180: Autonomous Mobile Robots



ECE 3400: Intelligent Physical Systems

End Game

5 weeks left till competition day

Coverage

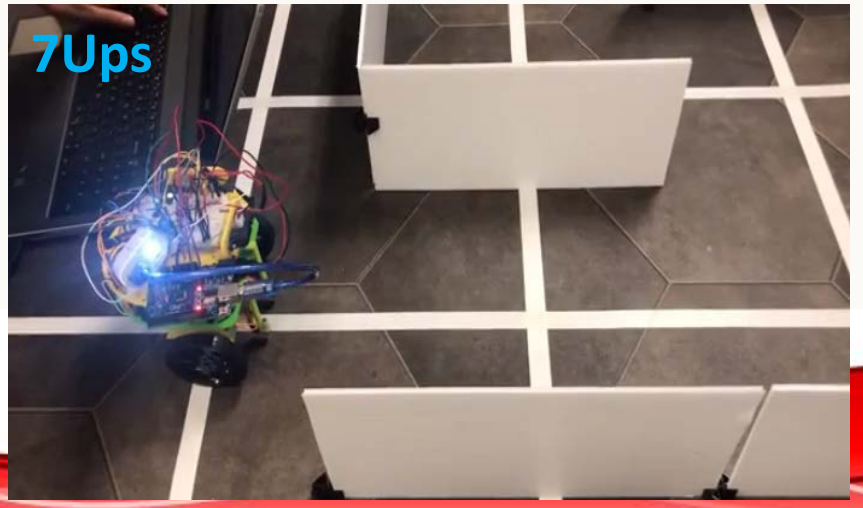
The full mazes will be 9 x 9 squares. The robot that maps the most of the maze correctly (wrt to walls and gaps) in a given round will receive 15 points. All other robots will receive scaled values thereof.

Treasures

- For every treasure which is located correctly: 1 point
- For every treasure that is located and color-identified correctly: 1 point
- For every treasure that is located and shape-identified correctly: 1 point
- For every discovery of a treasure that is not there: -1 point
- The minimum score per round is 0 points; the maximum is 20 points.

Can you explore the entire maze?

- 15s avg. for 6 squares
- 3.4min for 81 squares
- Unlikely, but possible.

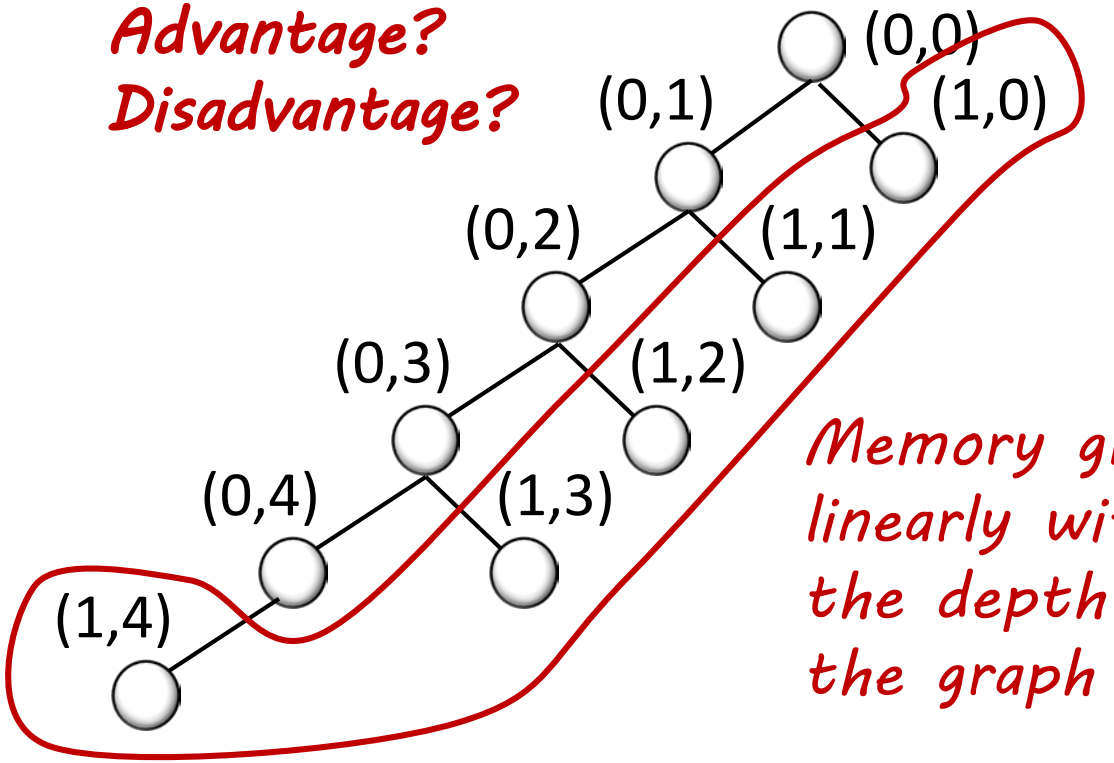


Algorithms and Search

Search order: N, E, S, W

- Depth First Search (DFS)

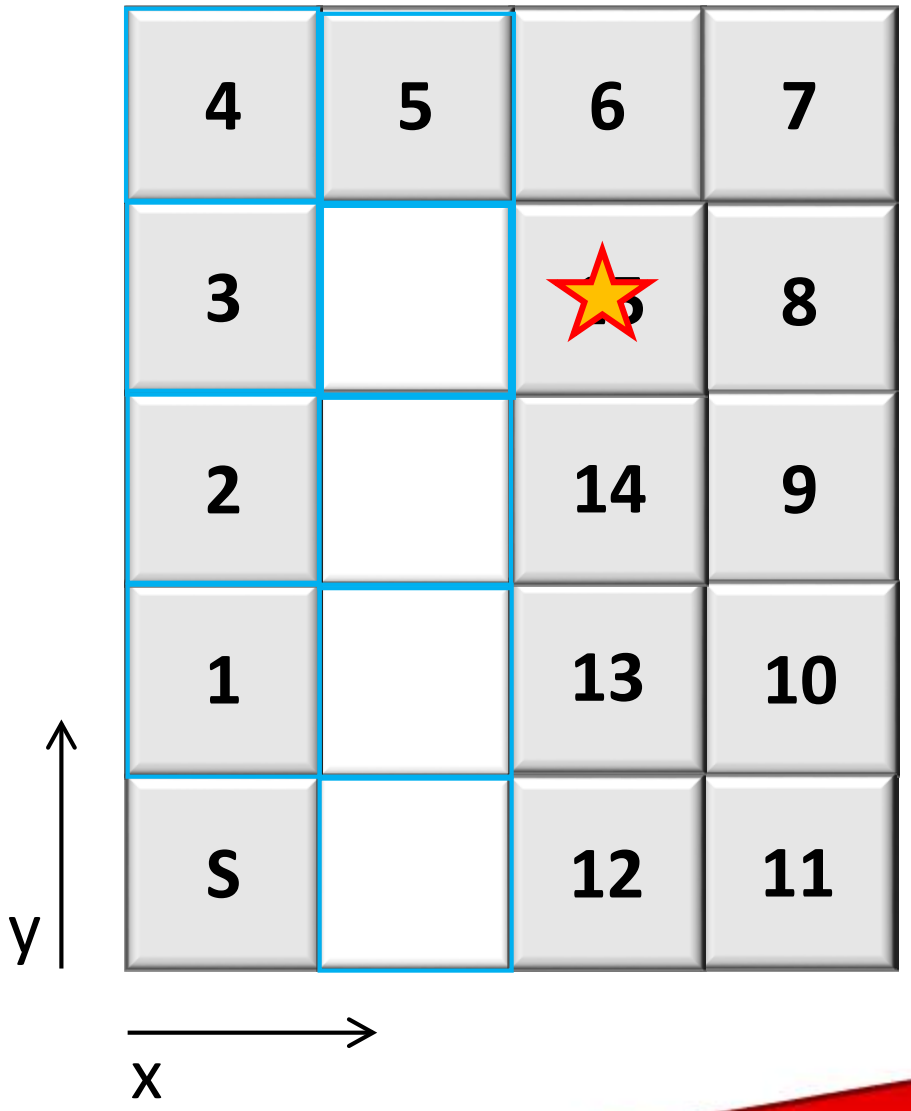
Advantage?
Disadvantage?



Memory grows linearly with the depth of the graph

and so on…

Find a treasure

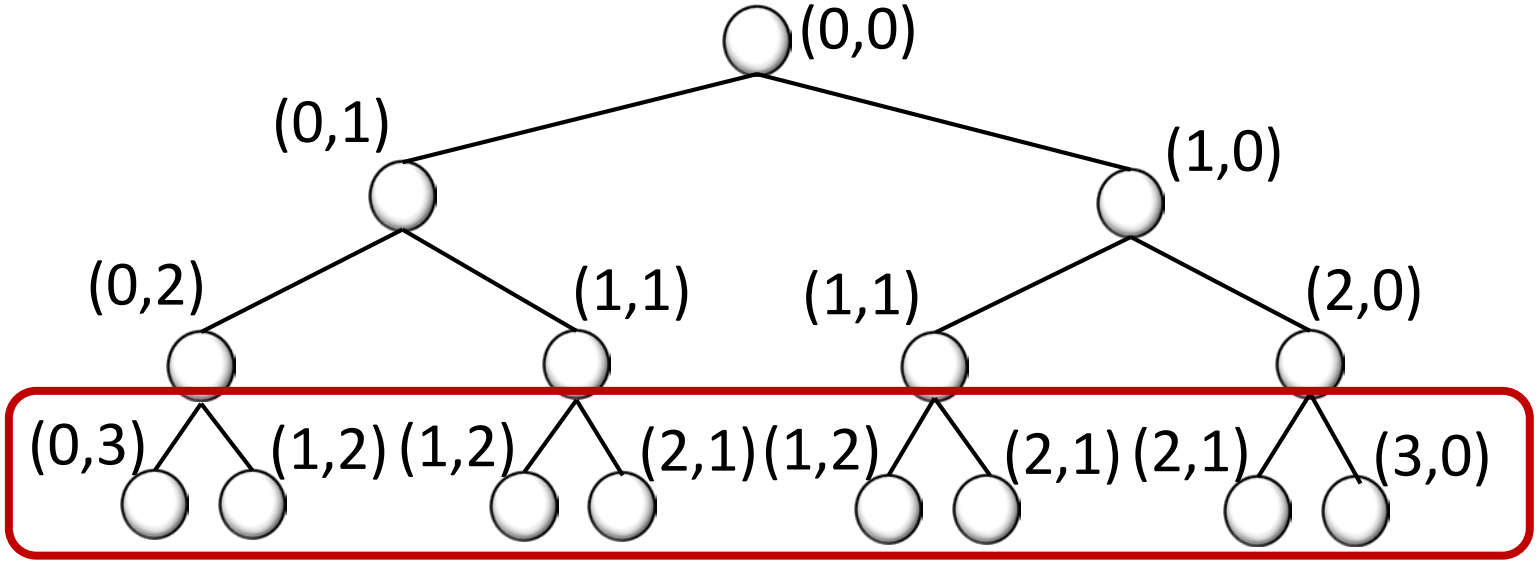


Algorithms and Search

Search order: N, E, S, W

- Depth First Search (DFS)
- Breadth First Search (BFS)

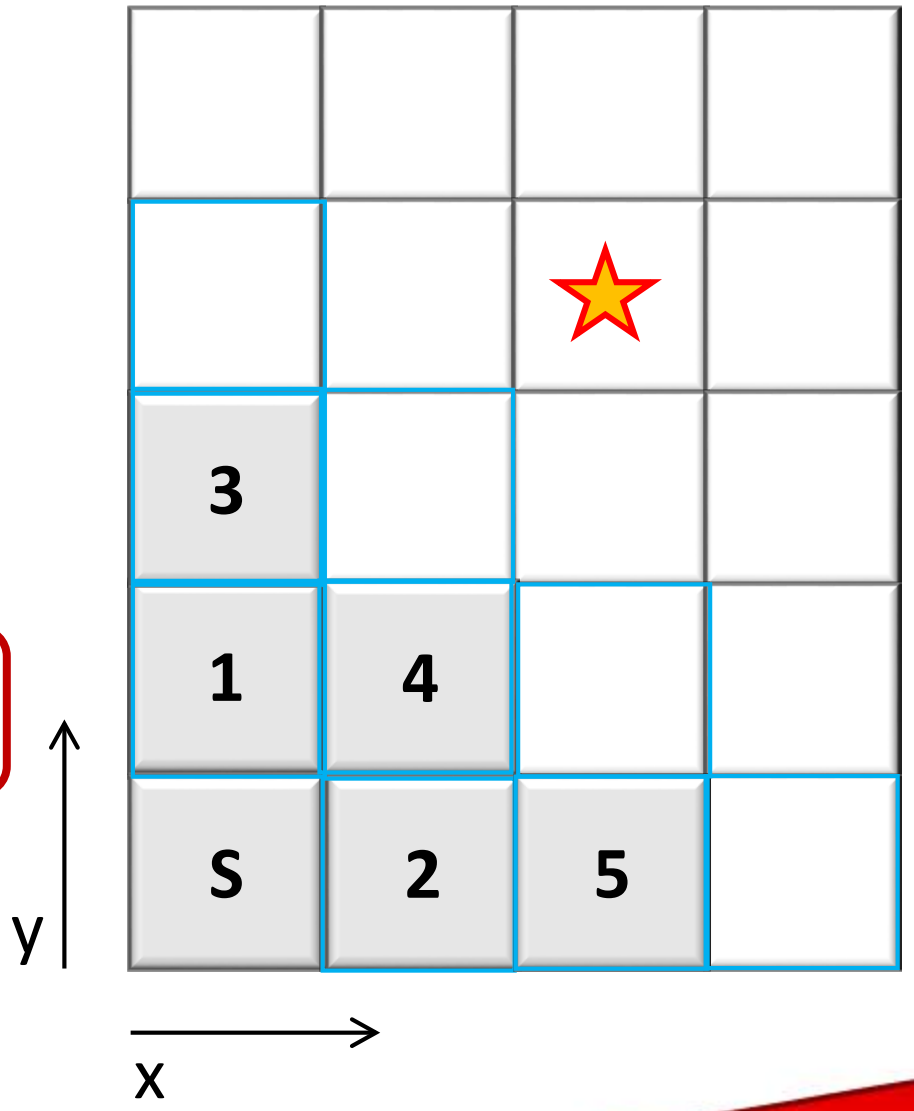
Advantage?
Disadvantage?



and so on…

Memory grows exponentially with the depth of the graph

Find a treasure

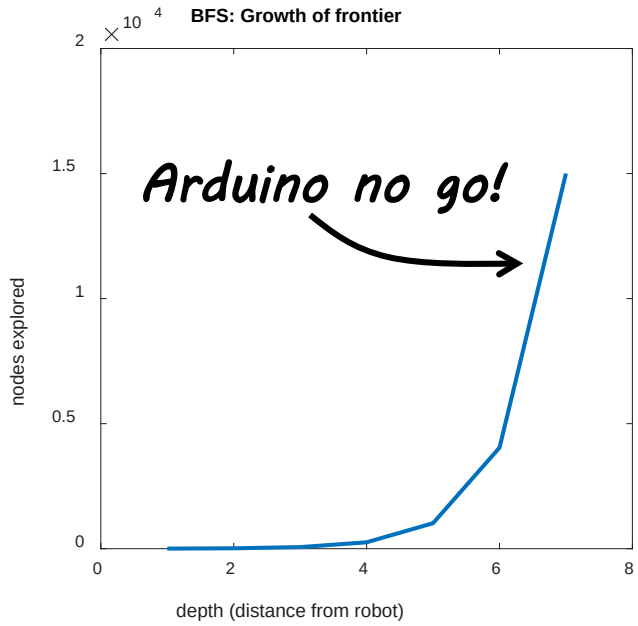


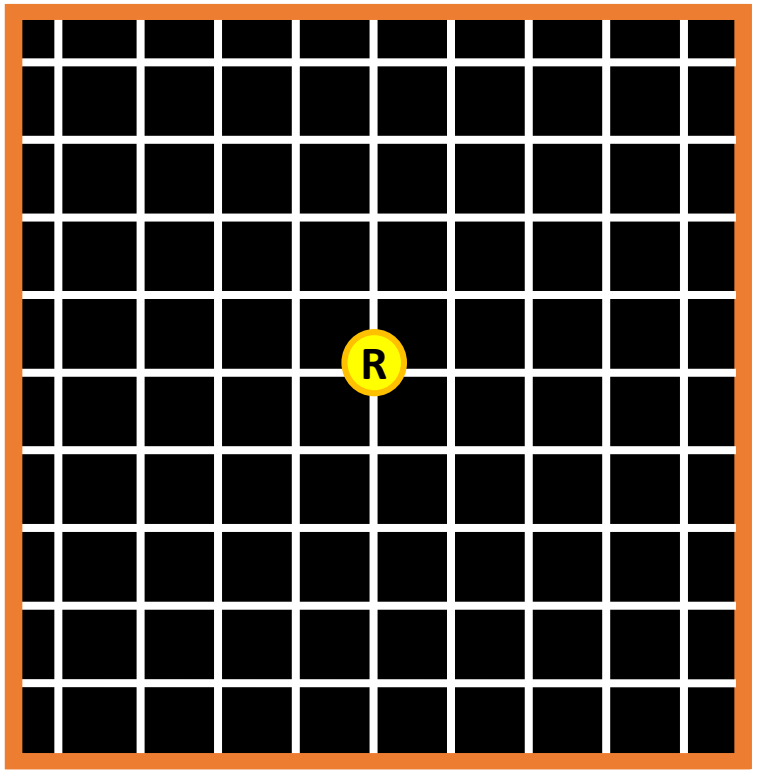
BFS: Memory and Computation

What do we need?

- Locations
- Example issue from last year…

```
n = state(init)
frontier.append(n)
while(frontier not empty)
    n = pull state from frontier
    if n = goal, return solution
    for all actions in n
        n' = a(n)
        frontier.append(n')
```





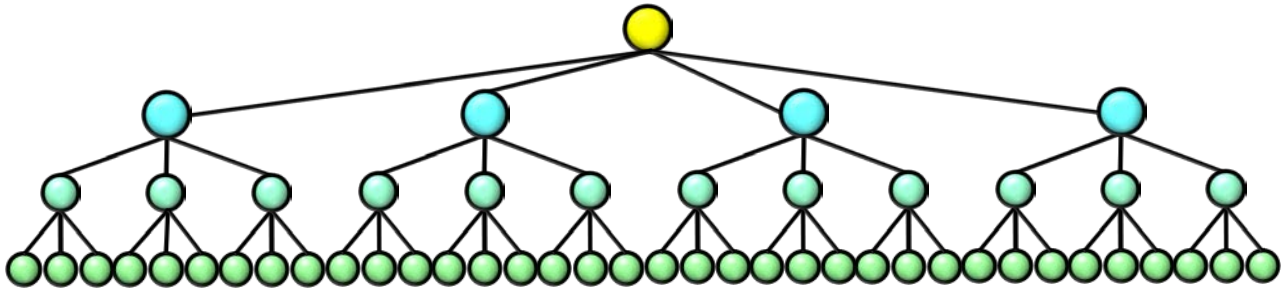
BFS: Memory and Computation

What do we need?

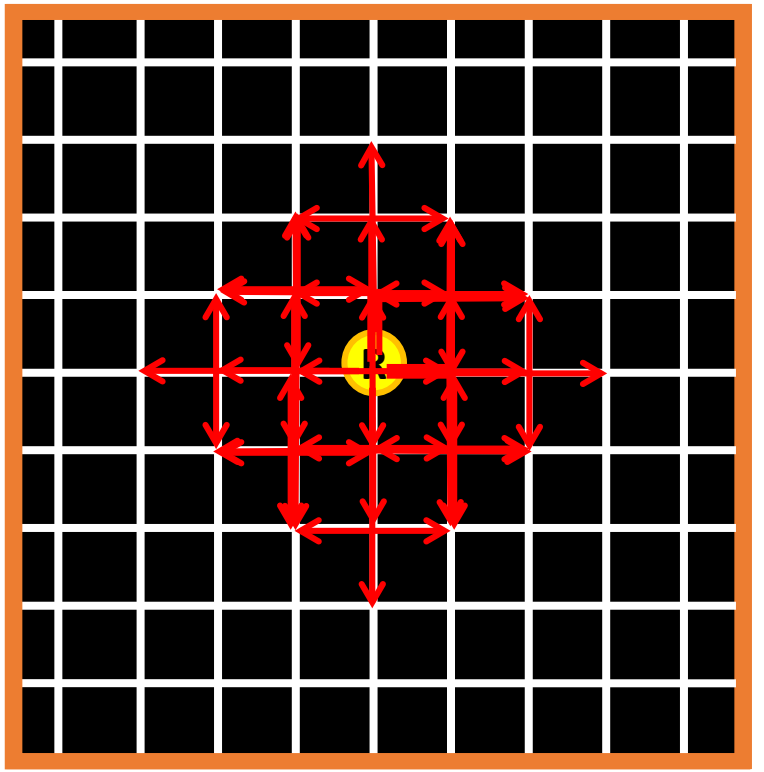
- Locations
- Parents

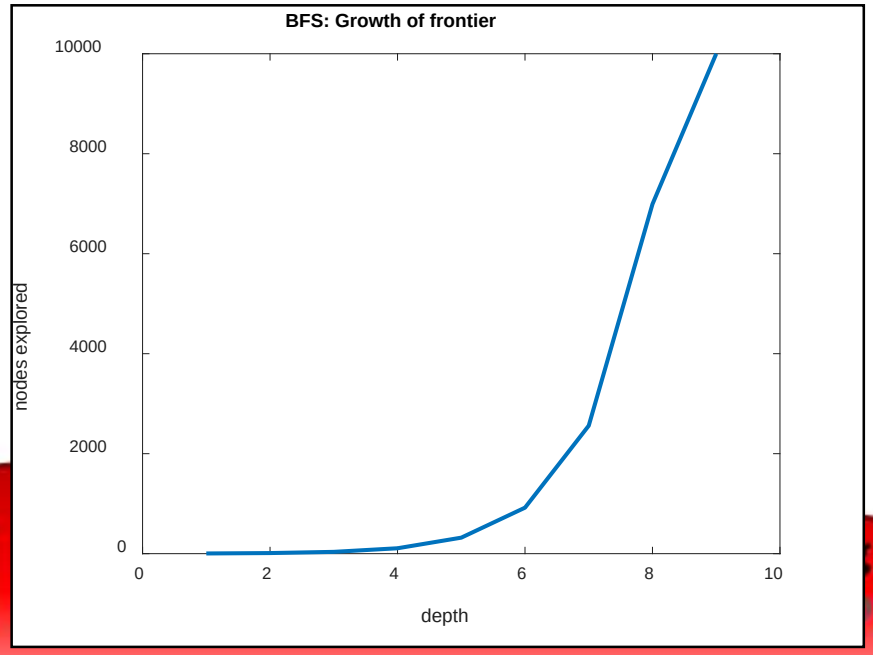
Frontier size:

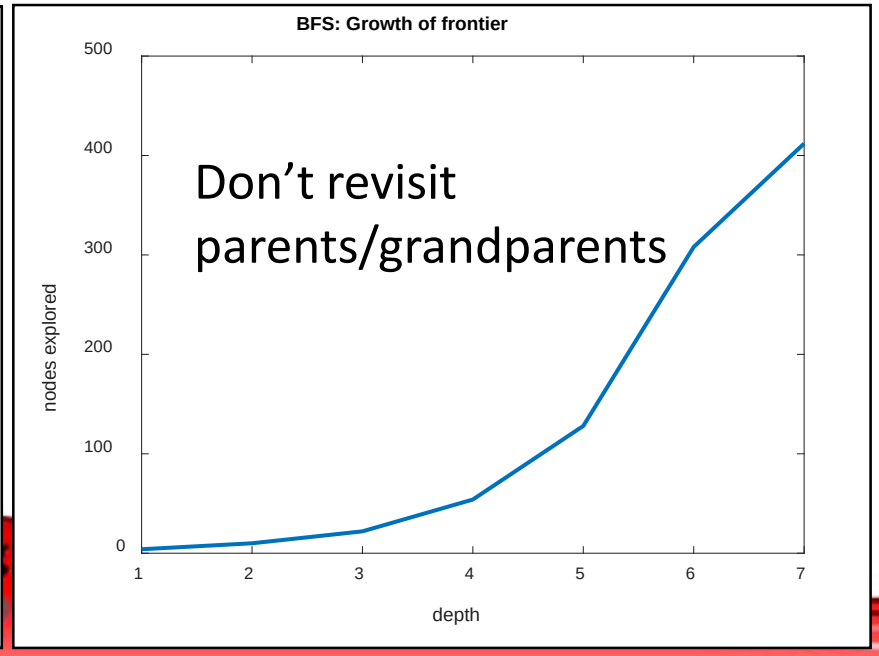
- 4
- 12
- 36
- mem = $4 \cdot 3^{n-1}$ (n = depth)



etc…



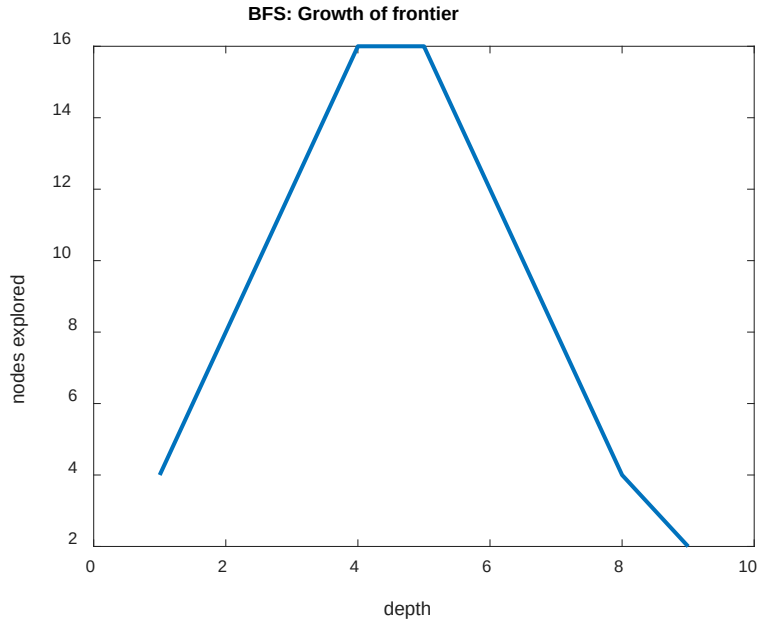




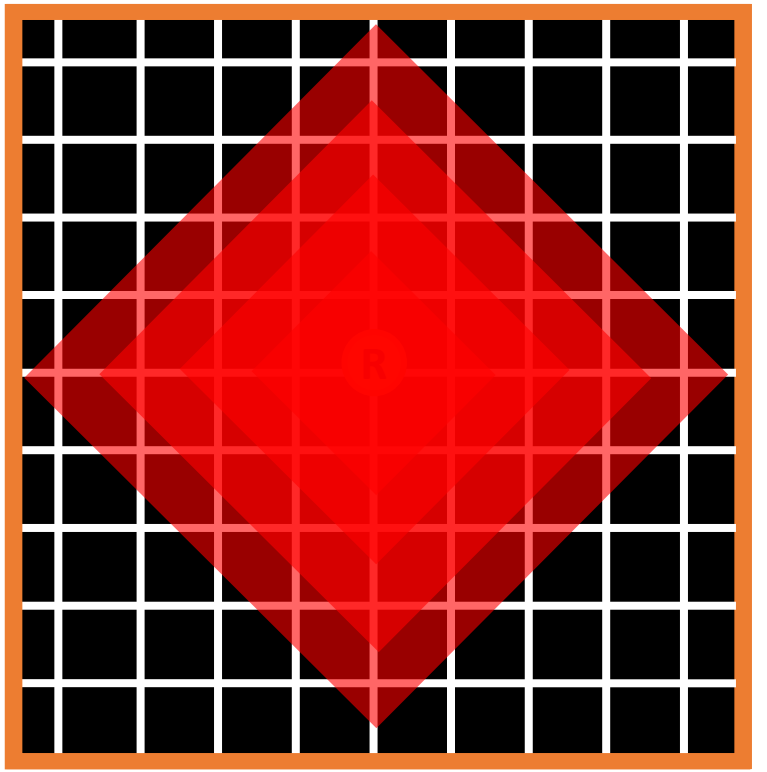
BFS: Memory and Computation

What do we need?

- Locations
- Parents
- Visited
  - *What is the maximum size of the frontier now?*



- *What is the issue with this approach?*
  - Store branches with lowest motion cost!

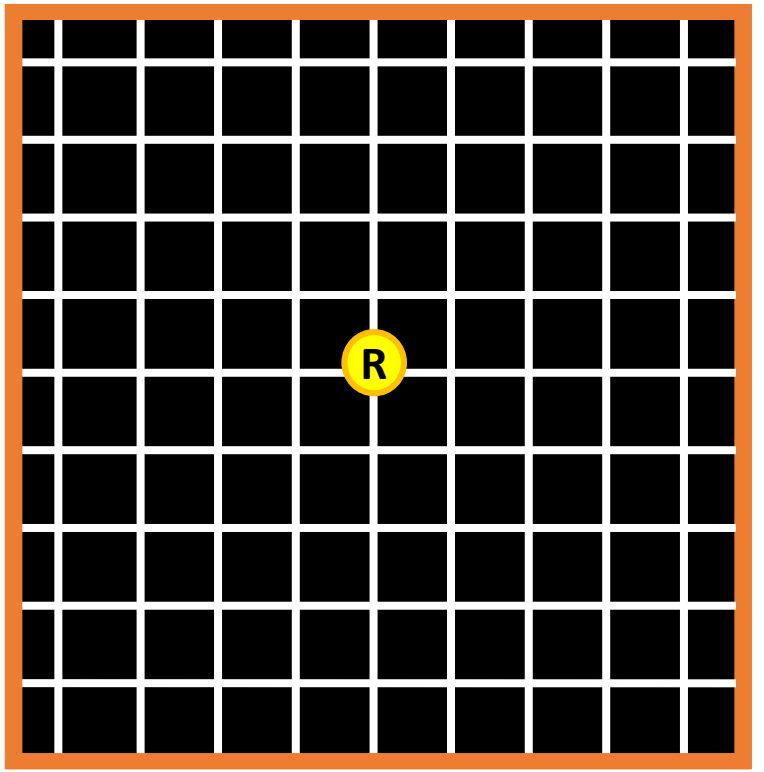


BFS: Memory and Computation

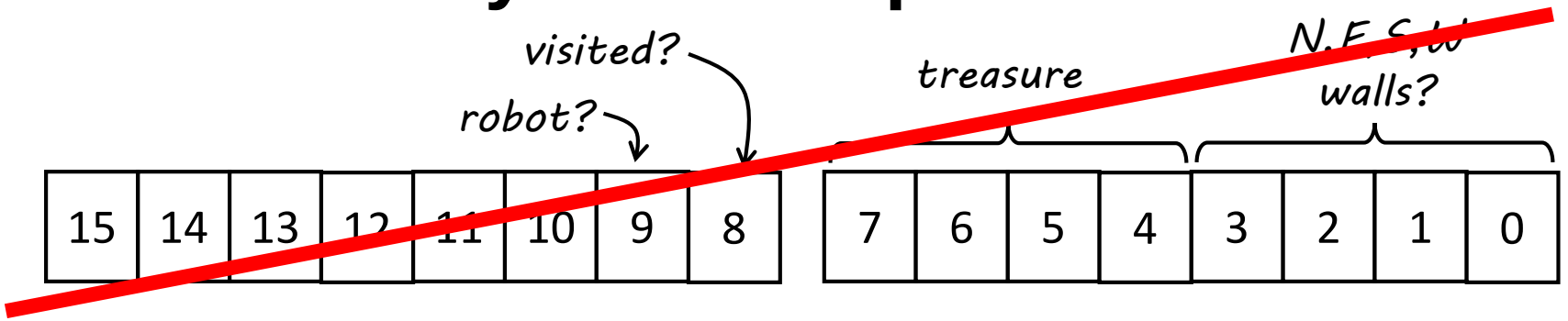
What do we need?

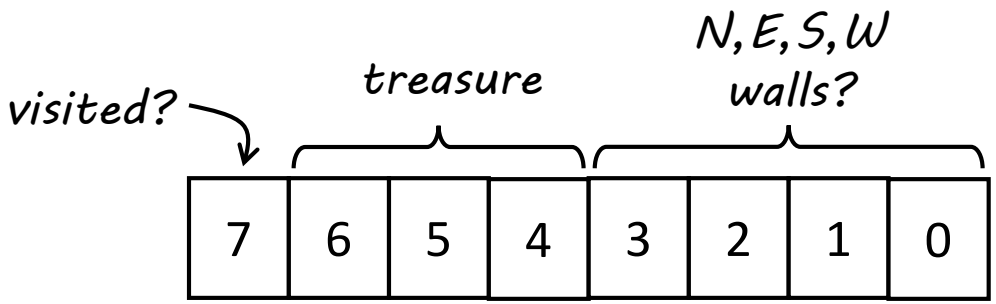
- Locations*
- Parents*
- Visited
- Cost*
- Action*

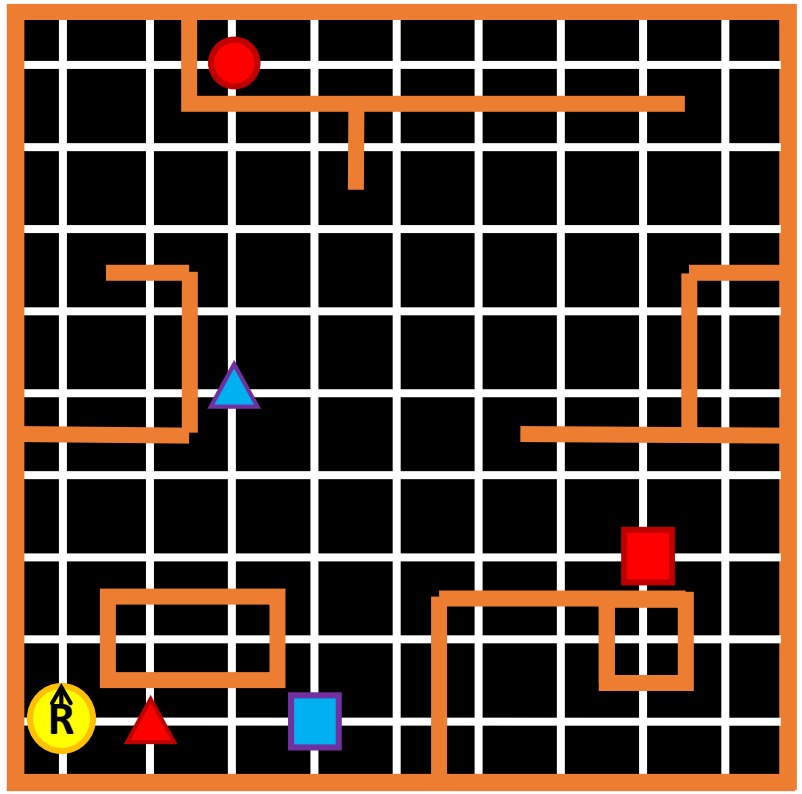
```
n = state(init)
frontier.append(n)
visited.append(n)
while(frontier not empty)
    n = pull state* from frontier
    if n = goal, return solution
    for all actions in n
        n' = a(n)
        if n' not visited or cost is lower
            frontier.append(n')
            visited.append(n')
```



BFS: Memory and Computation



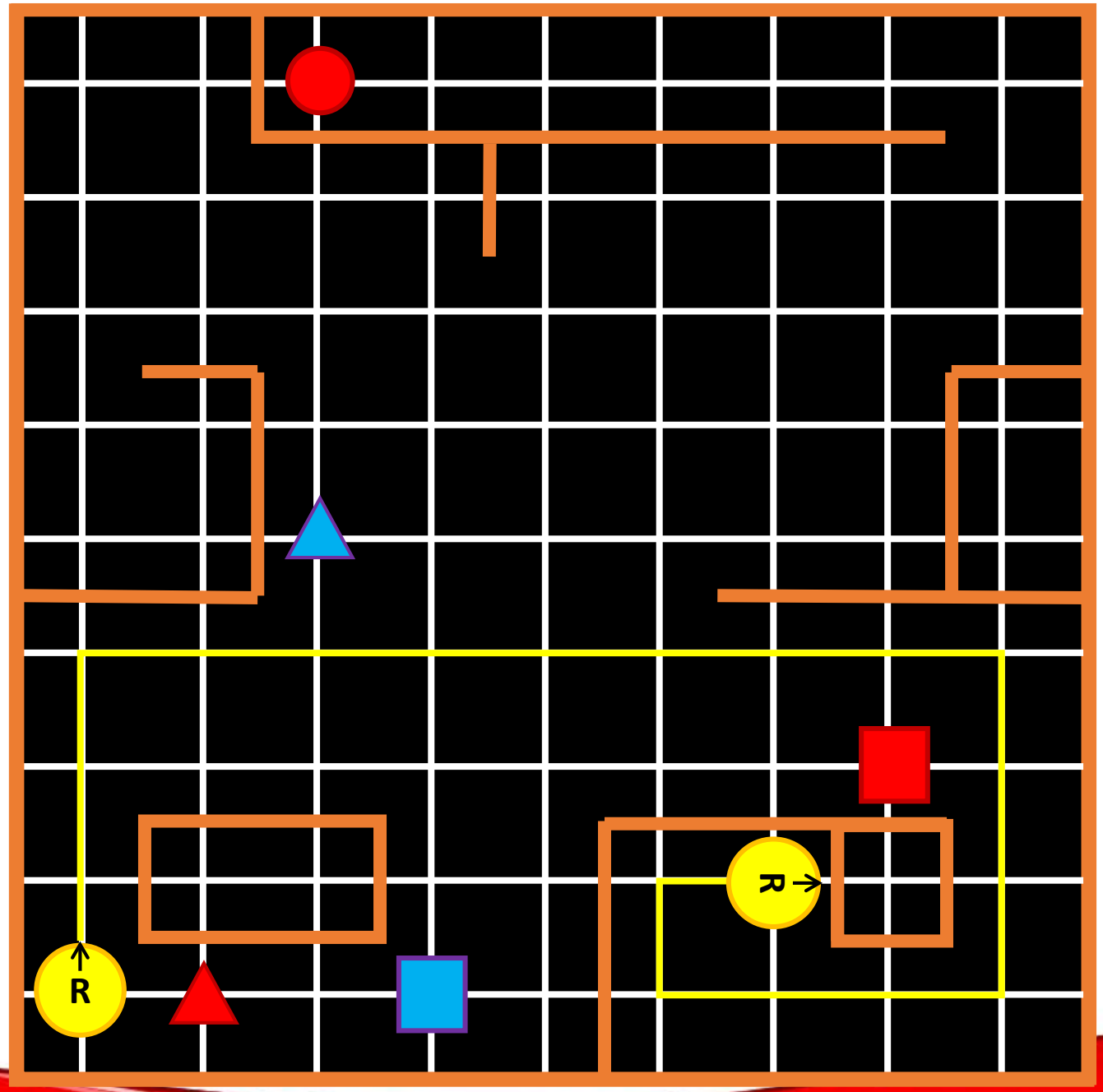




- …Teams are at 75-35% capacity (512B-1331B)
- Frontier (x,y-locations + parent + cost): 80B
- Visited: 81B, or 0B!
- ~~Maze: 162B~~
- Maze: 81B

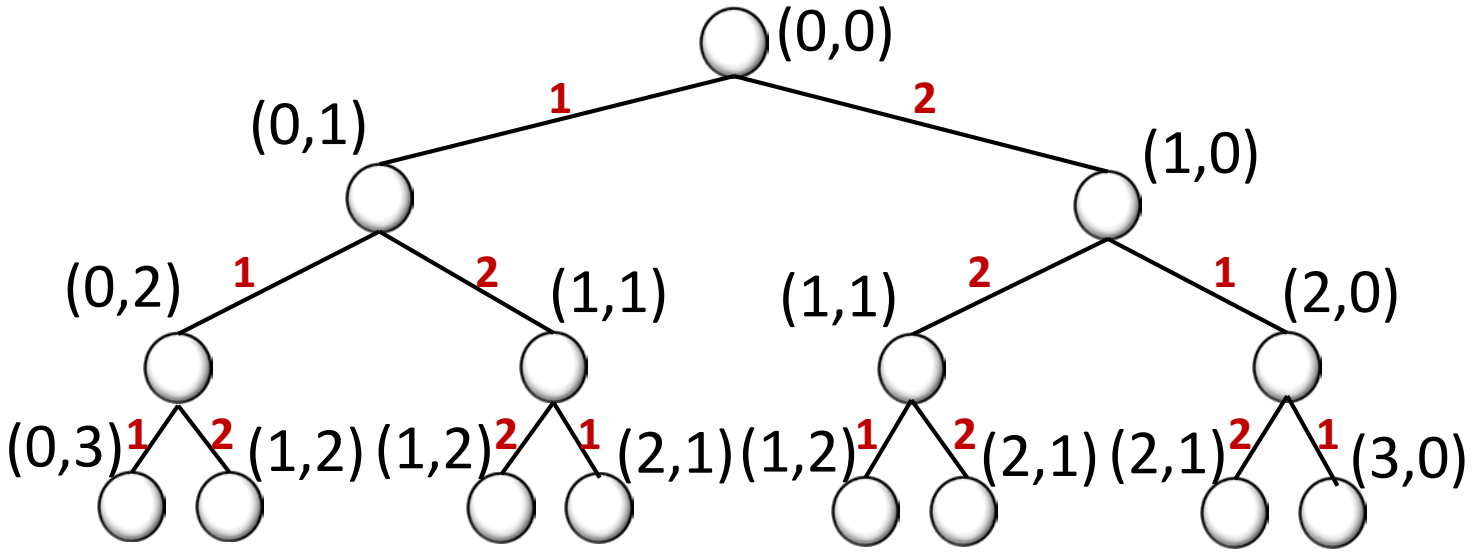
Maze Exploration

- **Depth First Search**
  - Search order:
    - Straight
    - Left, then straight
    - Right, then straight
    - U-turn, then straight
- **If stuck, find shortest path to the next frontier in the tree**
- *What treasure does the robot find first?*



Algorithms and Search

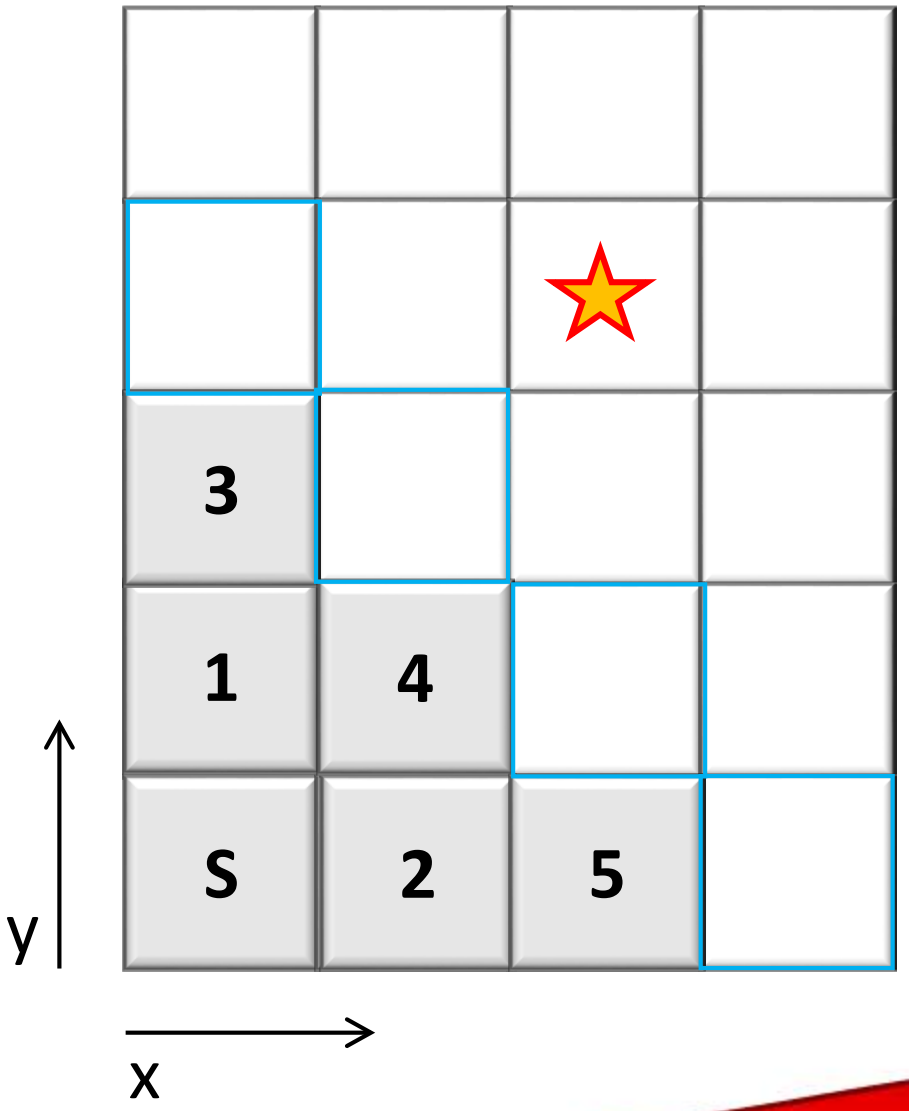
- Depth First Search (DFS)
- Breadth First Search (BFS)
- Add motion cost
- Dijkstra's to save computation/memory



and so on…

Search order: N, E, S, W

Find a treasure



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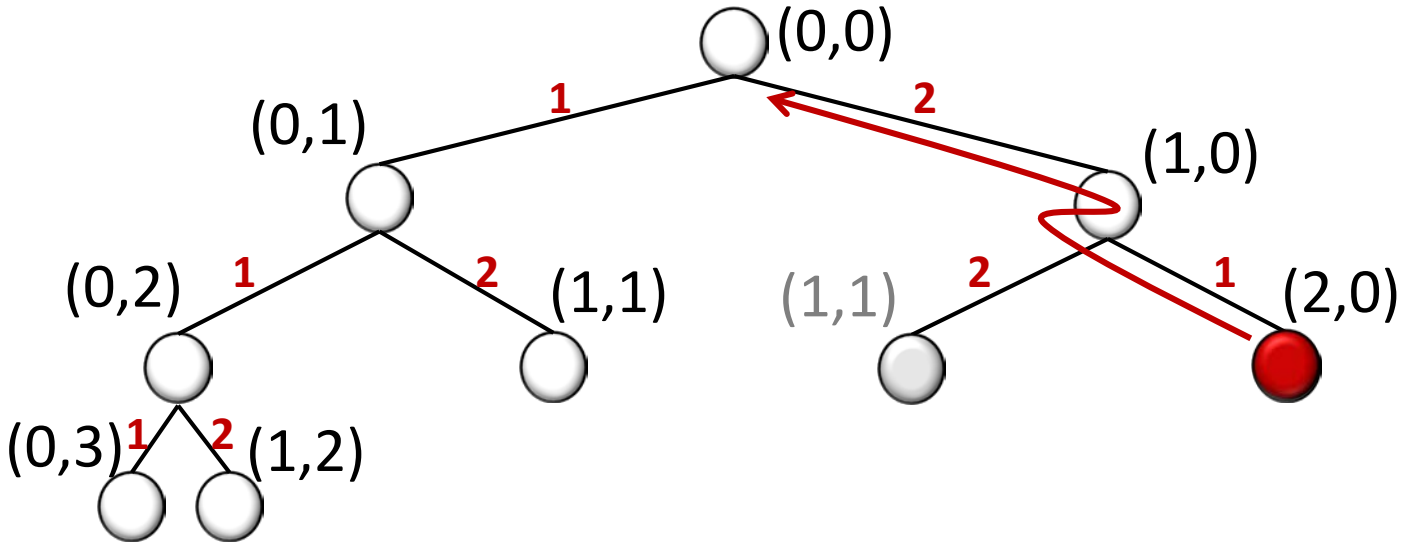

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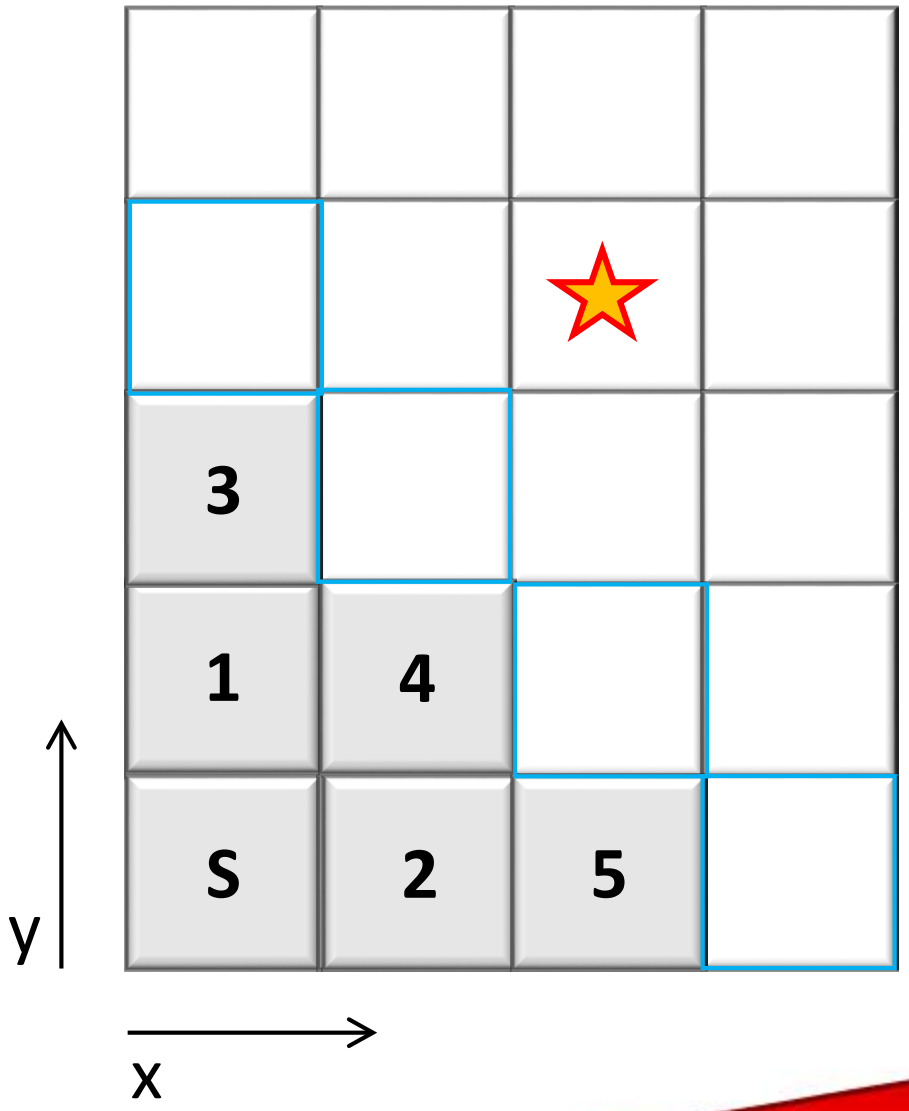
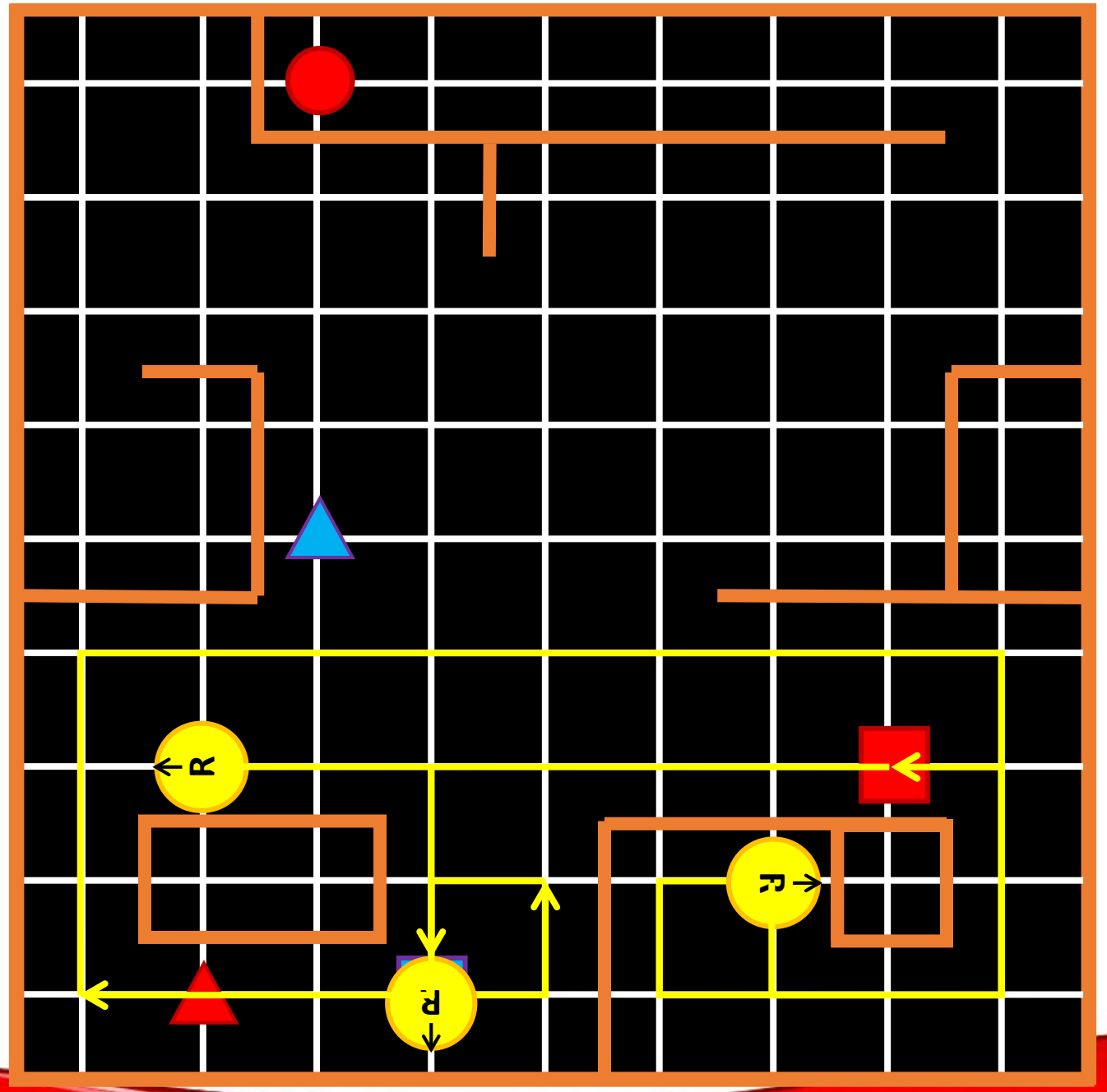
Search order: N, E, S, W

Find a treasure



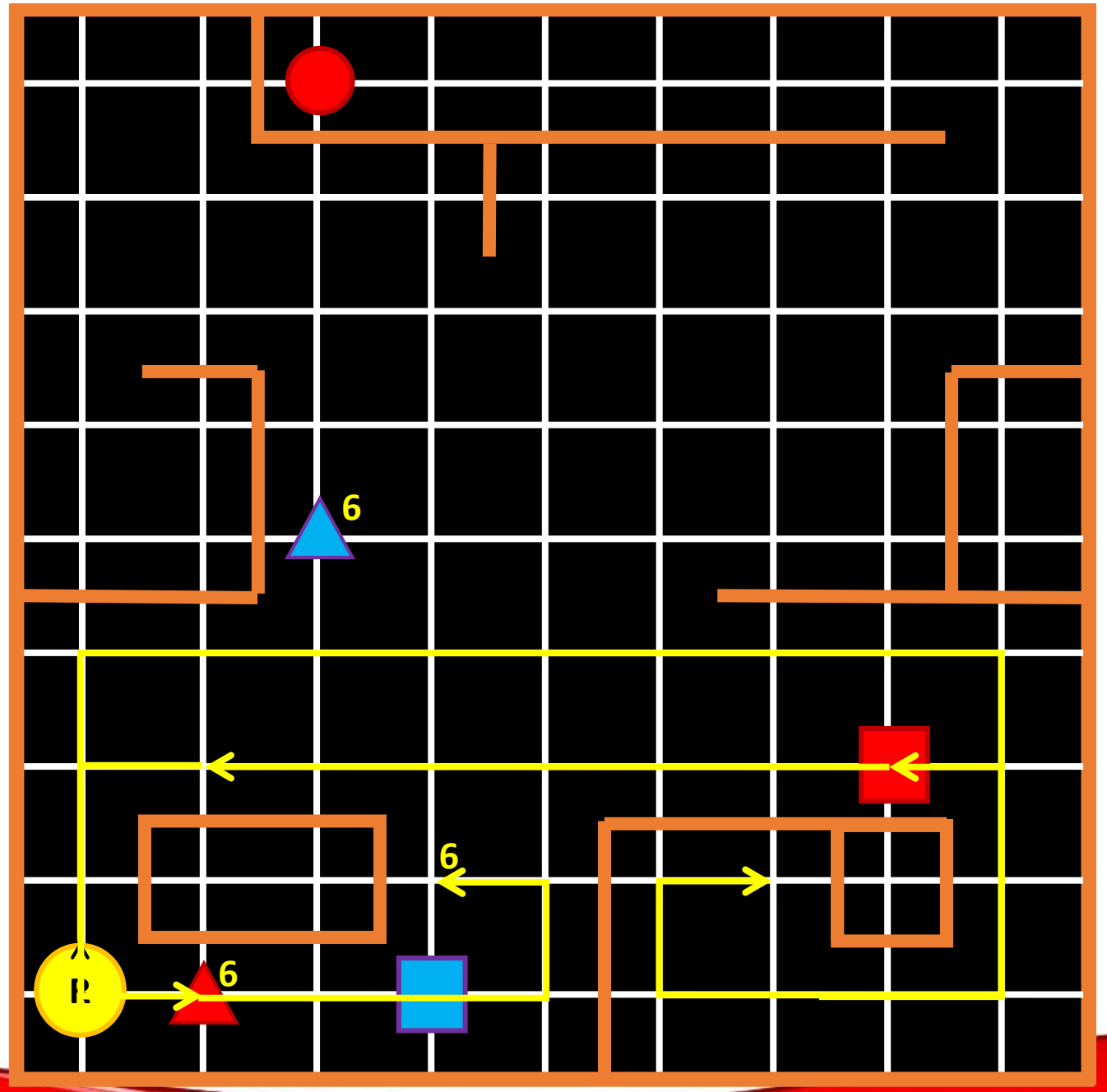
Maze Exploration

- **Depth First Search**
  - Search order:
    - Straight
    - Left, then straight
    - Right, then straight
    - U-turn, then straight
- **If stuck, find shortest path to the next frontier in the tree**
- *What treasure does the robot find first?*
- *What treasure does the robot find second?*
- *Could we be more efficient?*



Maze Exploration

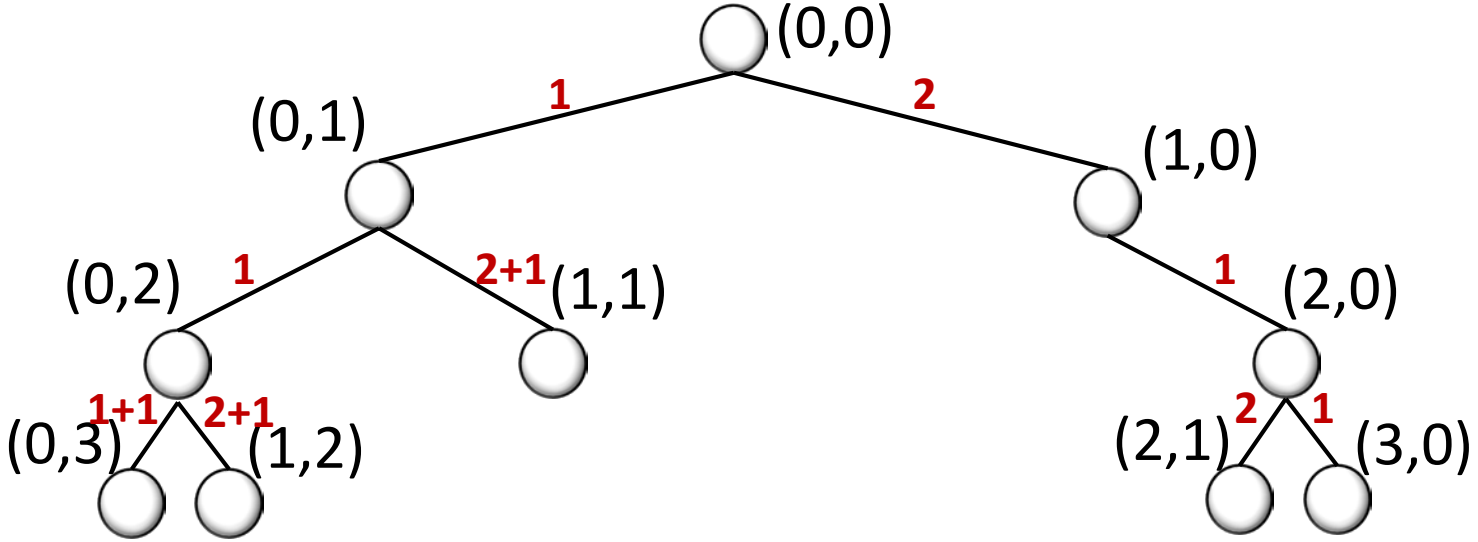
- **Dijkstra to find the next frontier**
  - Search order:
    - Straight
    - Left, then straight
    - Right, then straight
    - U-turn, then straight
- *What treasure does the robot find first?*
- *Next treasure?*
- Extra computation (Dijkstra for every square), but *maybe better*
- *Better path planning?*
  - Add cost for revisiting nodes



Maze Exploration

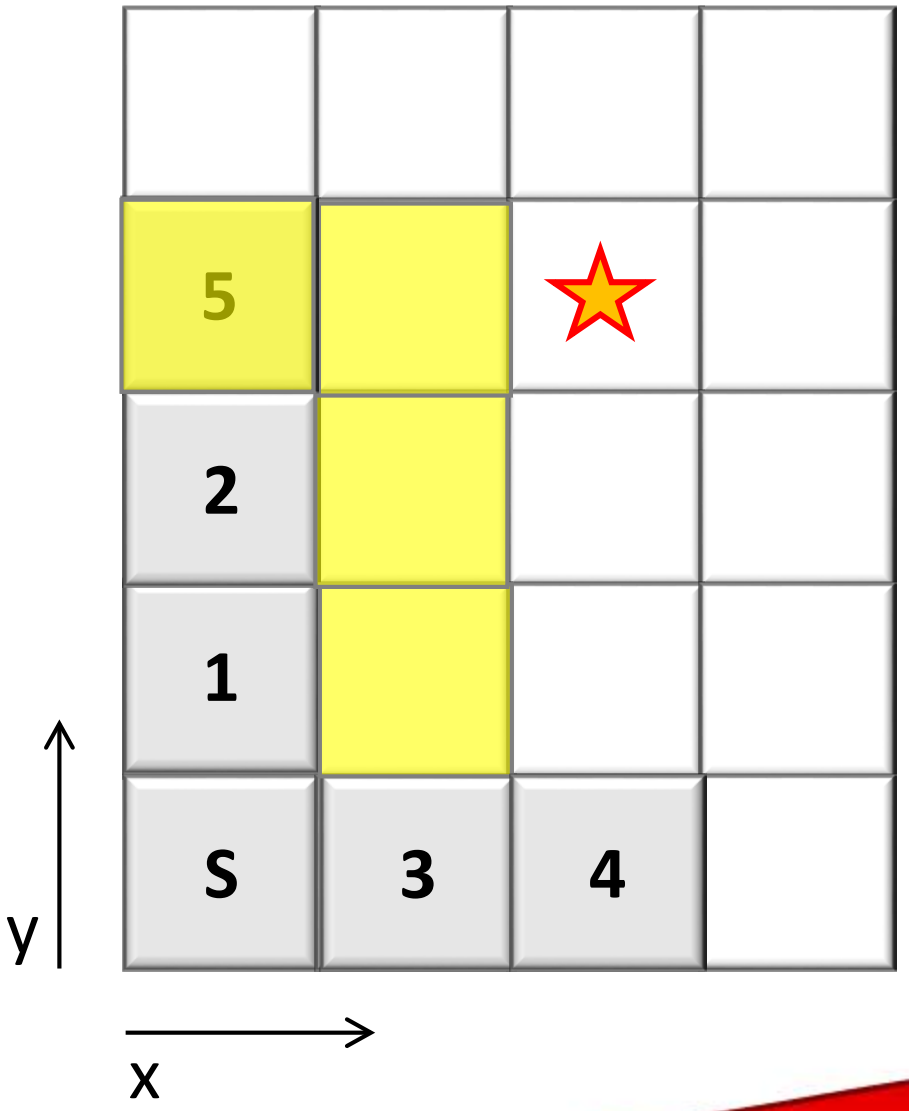
Search order: N, E, S, W

- Dijkstra's Search ← *Only reasons about the cost to get there…*
- *Could you be more efficient by looking ahead?*



and so on…

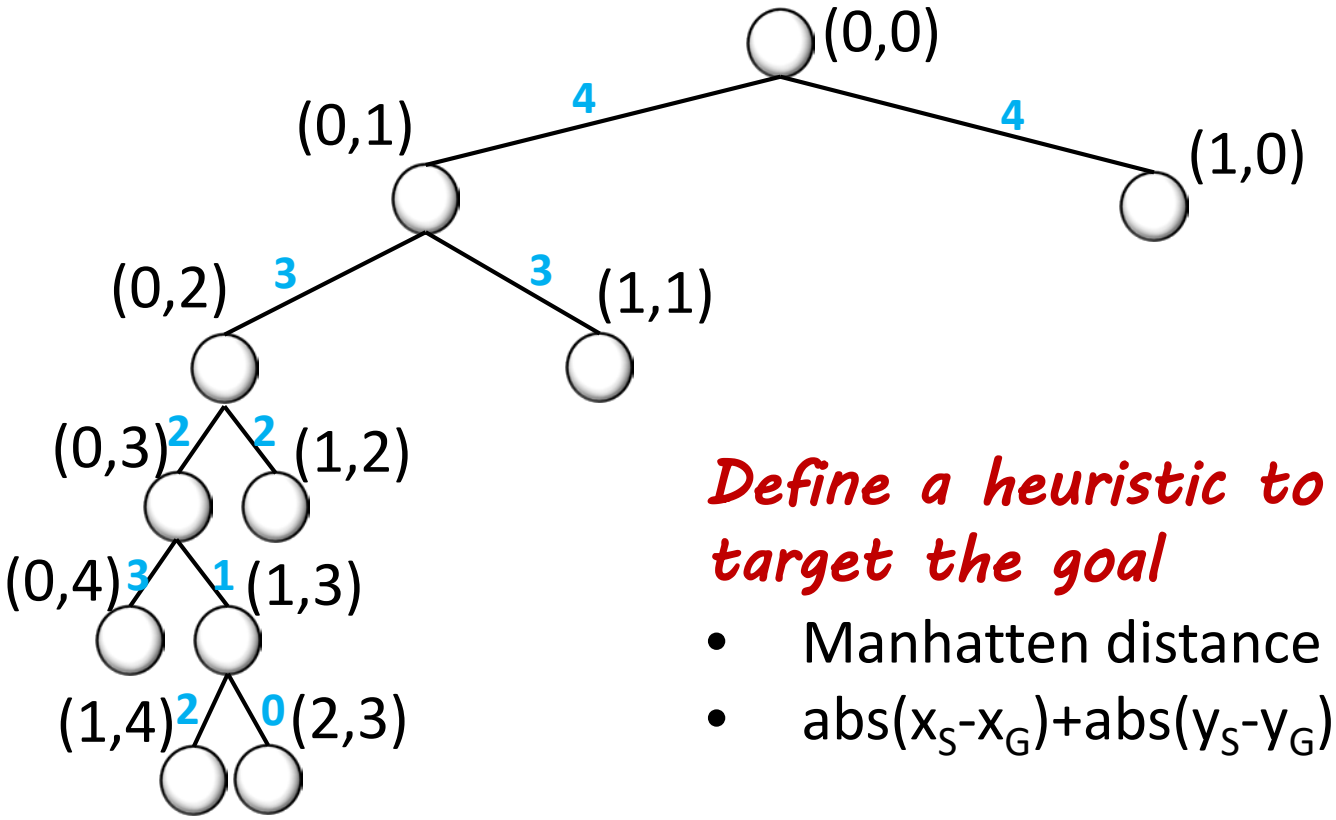
Find a treasure



Informed Search

Search order: N, E, S, W

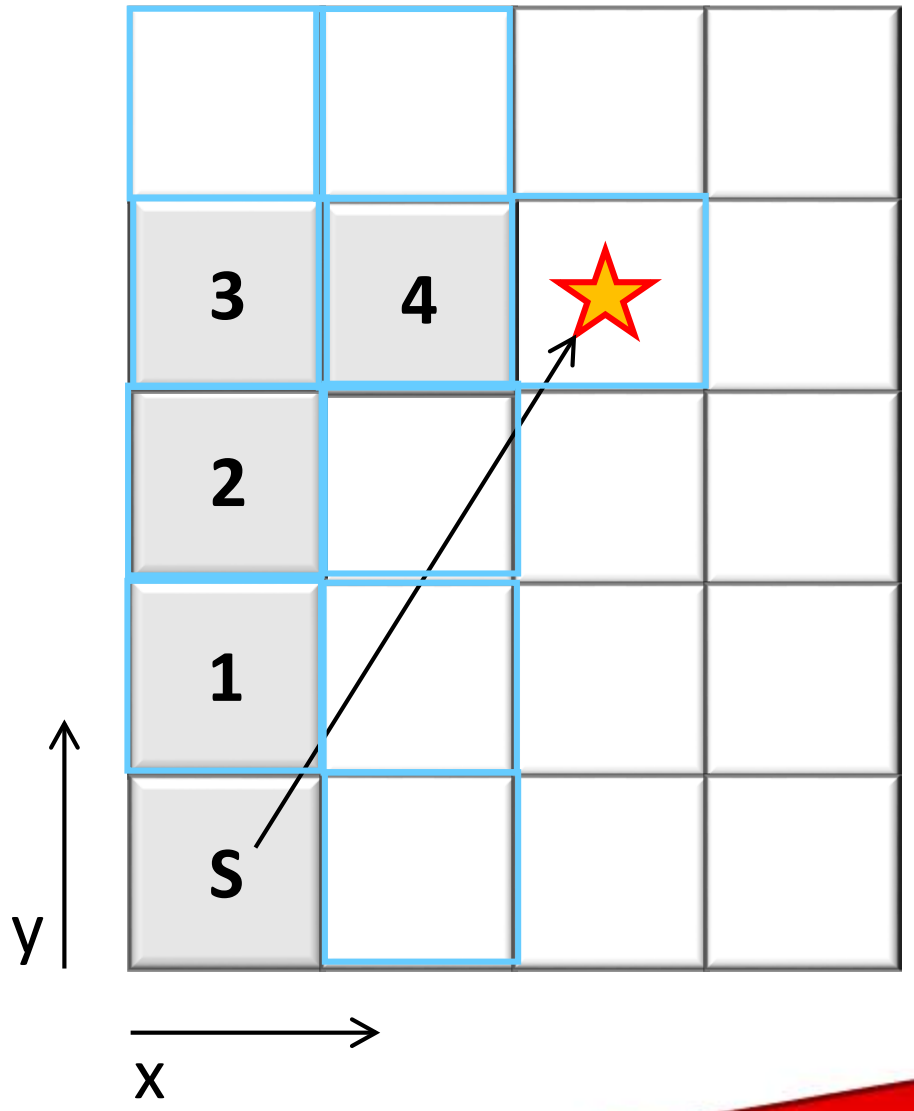
- Greedy Search



Define a heuristic to target the goal

- Manhatten distance
- $abs(x_S-x_G)+abs(y_S-y_G)$

Find a treasure



Informed Search

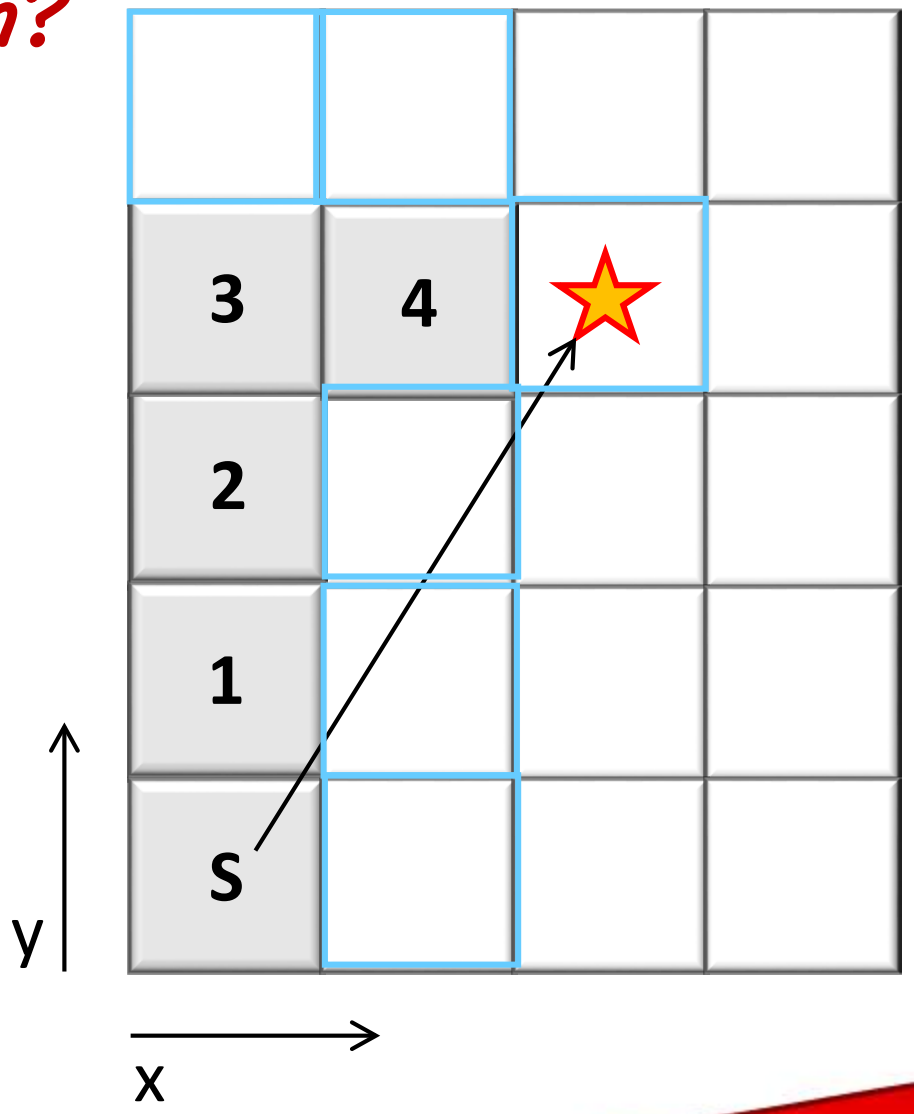
Search order: N, E, S, W

- Greedy Search

Cause for concern?

```
n = state(init)
frontier.append(n)
while(frontier not empty)
   n = pull state from frontier
   visited.append(n)
   if n = goal, return solution
   for all actions in n
      n' = a(n)
      if n' not visited
            priority = heuristic(goal,n')
            frontier.append(priority)
```

Find a treasure

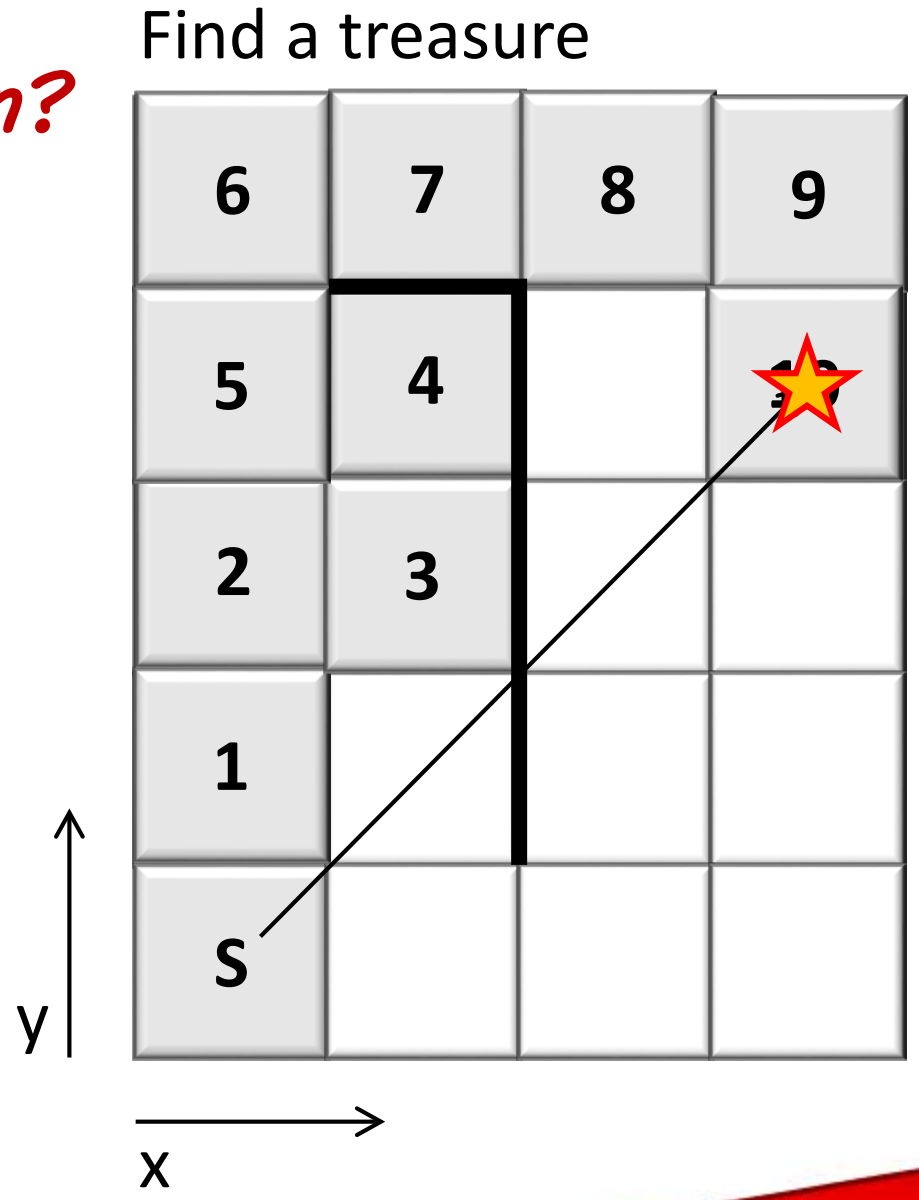


Informed Search

Search order: N, E, S, W

- Greedy Search
  - Faster, but does not guarantee optimal

Cause for concern?



Informed Search

- Breadth First Search
  - Guarantee: Finds a path
  - Searches *everything*
- Dijkstra's Algorithm
  - Guarantee: Finds the shortest path
  - …but it wastes time exploring in directions that aren't promising
- Greedy Search
  - Guarantee: Finds a path
  - …only explores promising directions

Considers parent cost

Considers goal

A*

Can we do better?

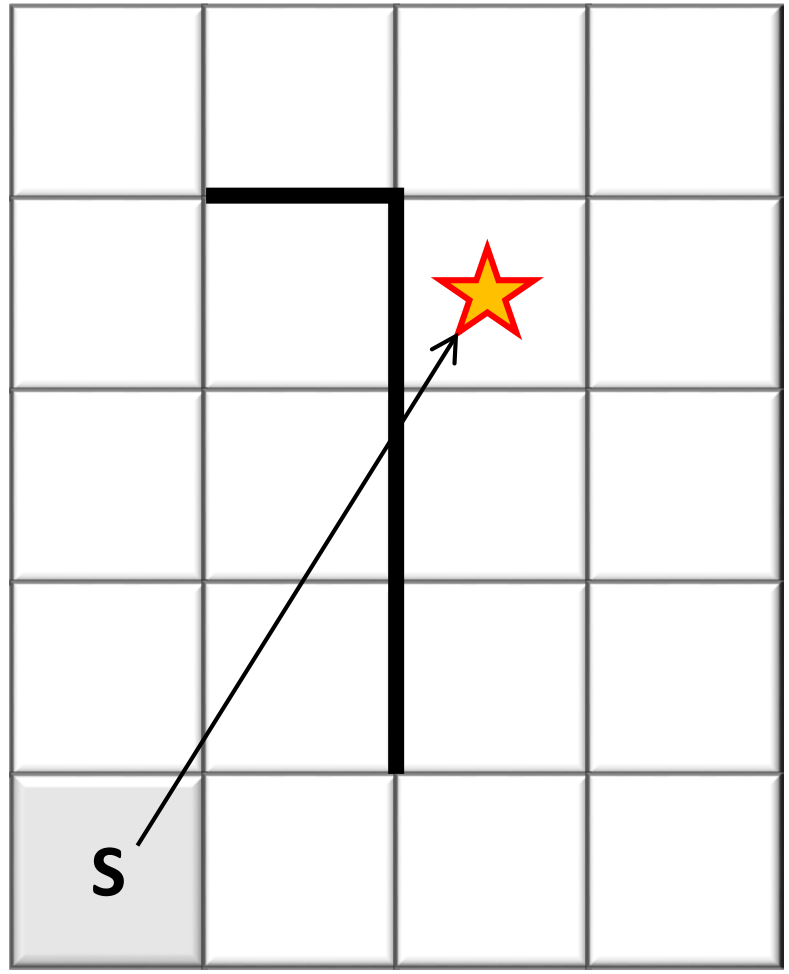
Informed Search

Search order: N, E, S, W

- A* ("A-star")

```
n = state(init)
frontier.append(n)
while(frontier not empty)
   n = pull state from frontier
   if n = goal, return solution
   for all actions in n
      n' = a(n)
      if ((n' not visited or
         (visited and n'.cost < n_old.cost))
            priority = heuristic(goal,n')+cost
            frontier.append(priority)
            visited.append(n')
```

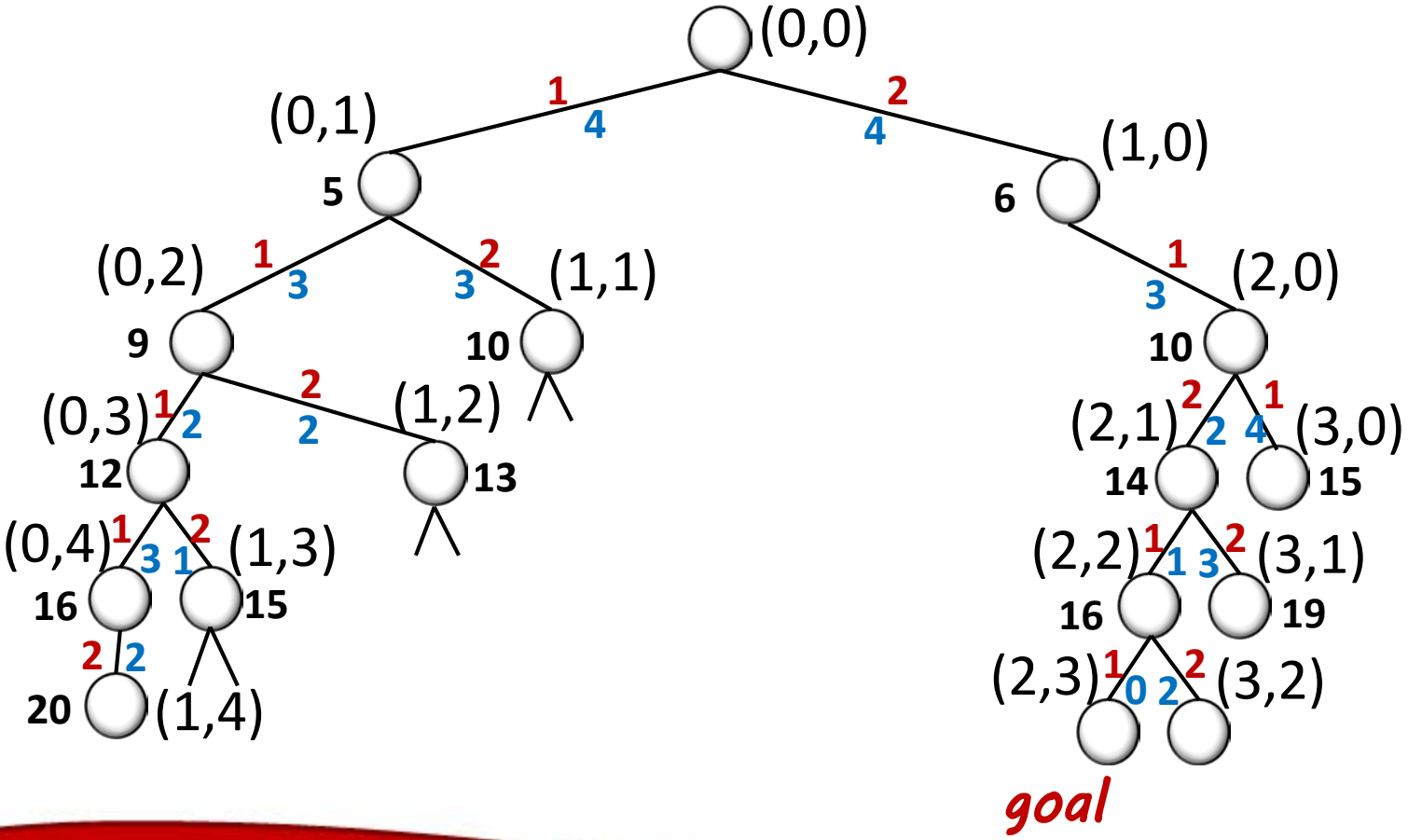
Find a treasure



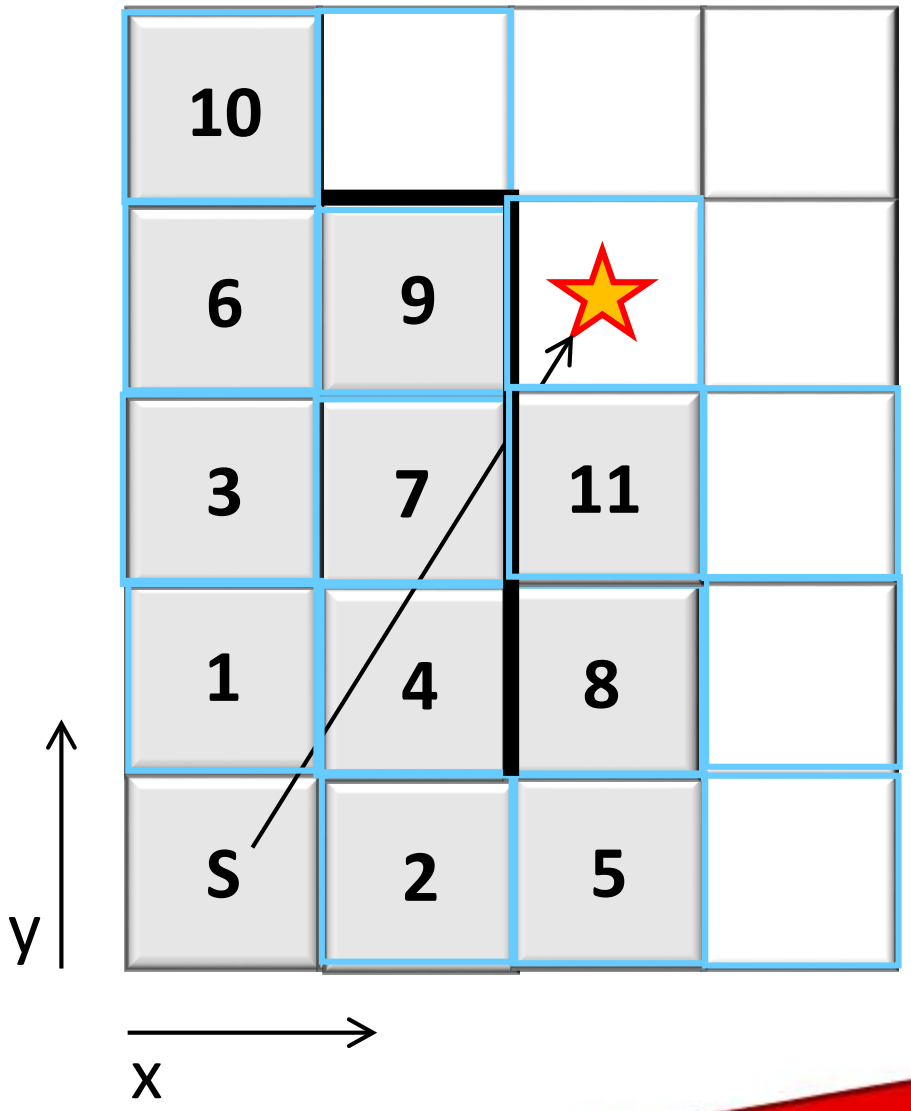
Informed Search

Search order: N, E, S, W

- A* ("A-star")
  - Cost and goal heuristic



Find a treasure



Informed Search

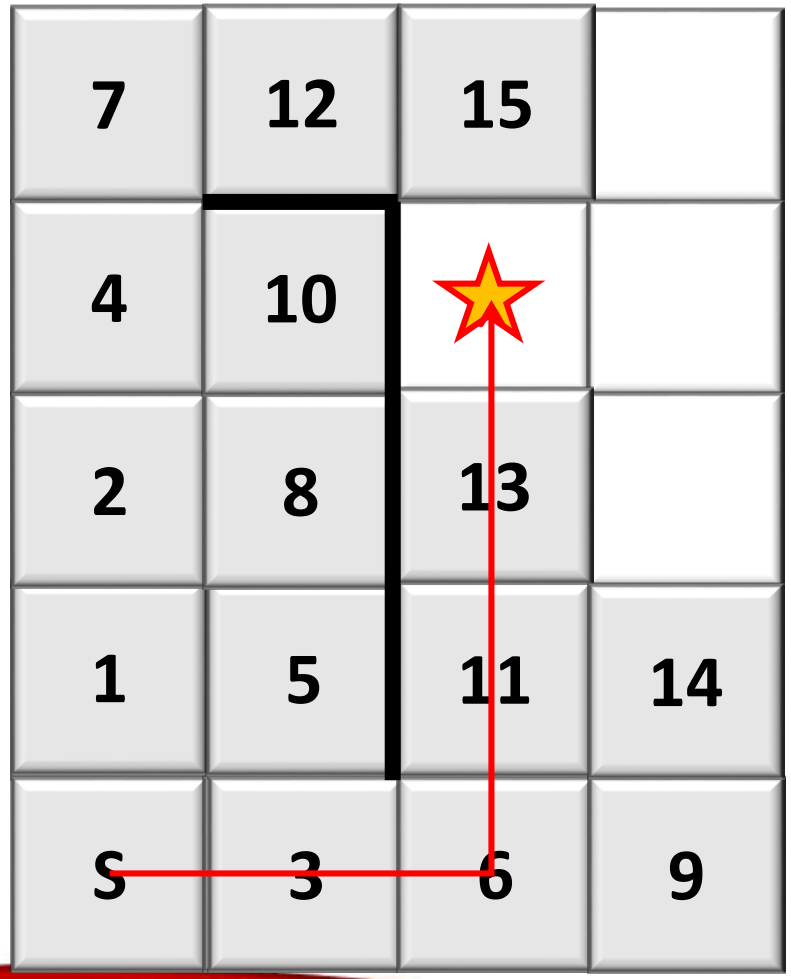
admissible heuristic

inadmissible heuristic

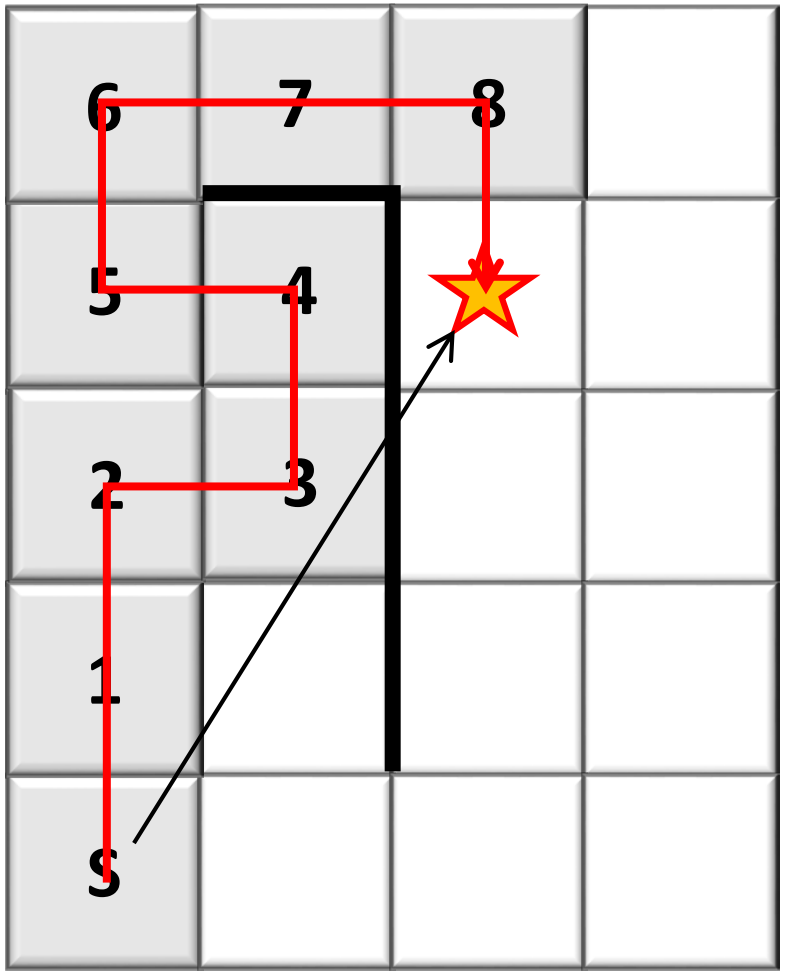
- What if the heuristic is too optimistic?
  - Estimated cost < true cost
- What if the heuristic is too pessimistic?
  - Estimated cost > true cost
  - No longer guaranteed to be optimal
- What if the heuristic is just right?
  - Pre-compute the cost between all nodes
  - Feasible for you?

Summary

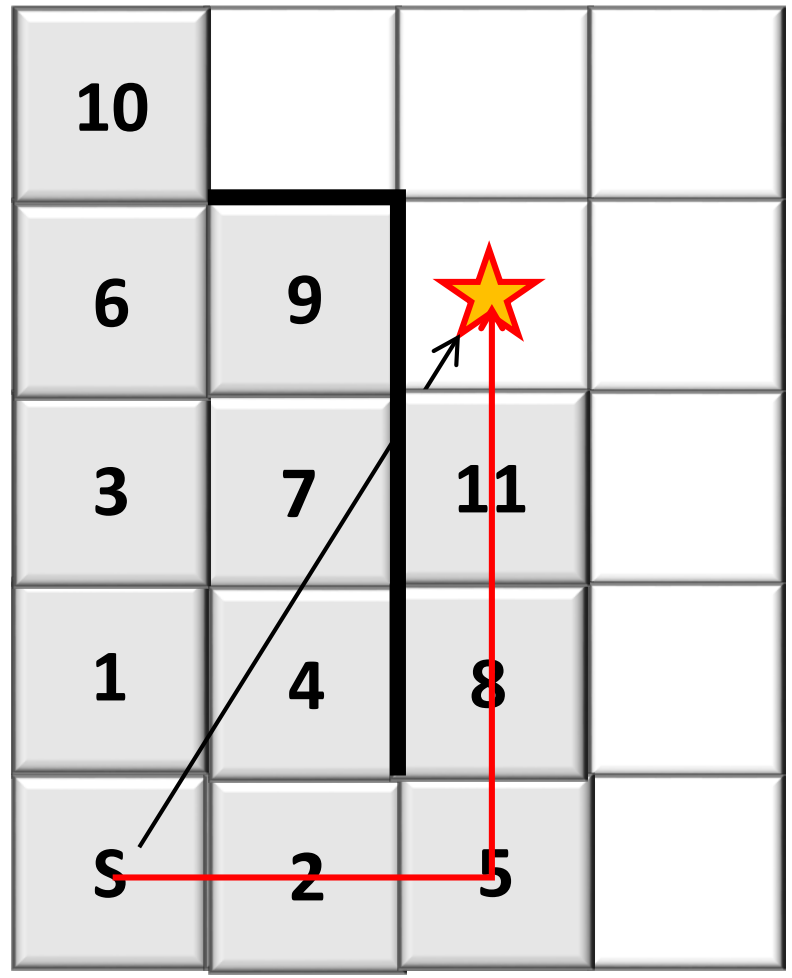
Dijkstra *minimum path*

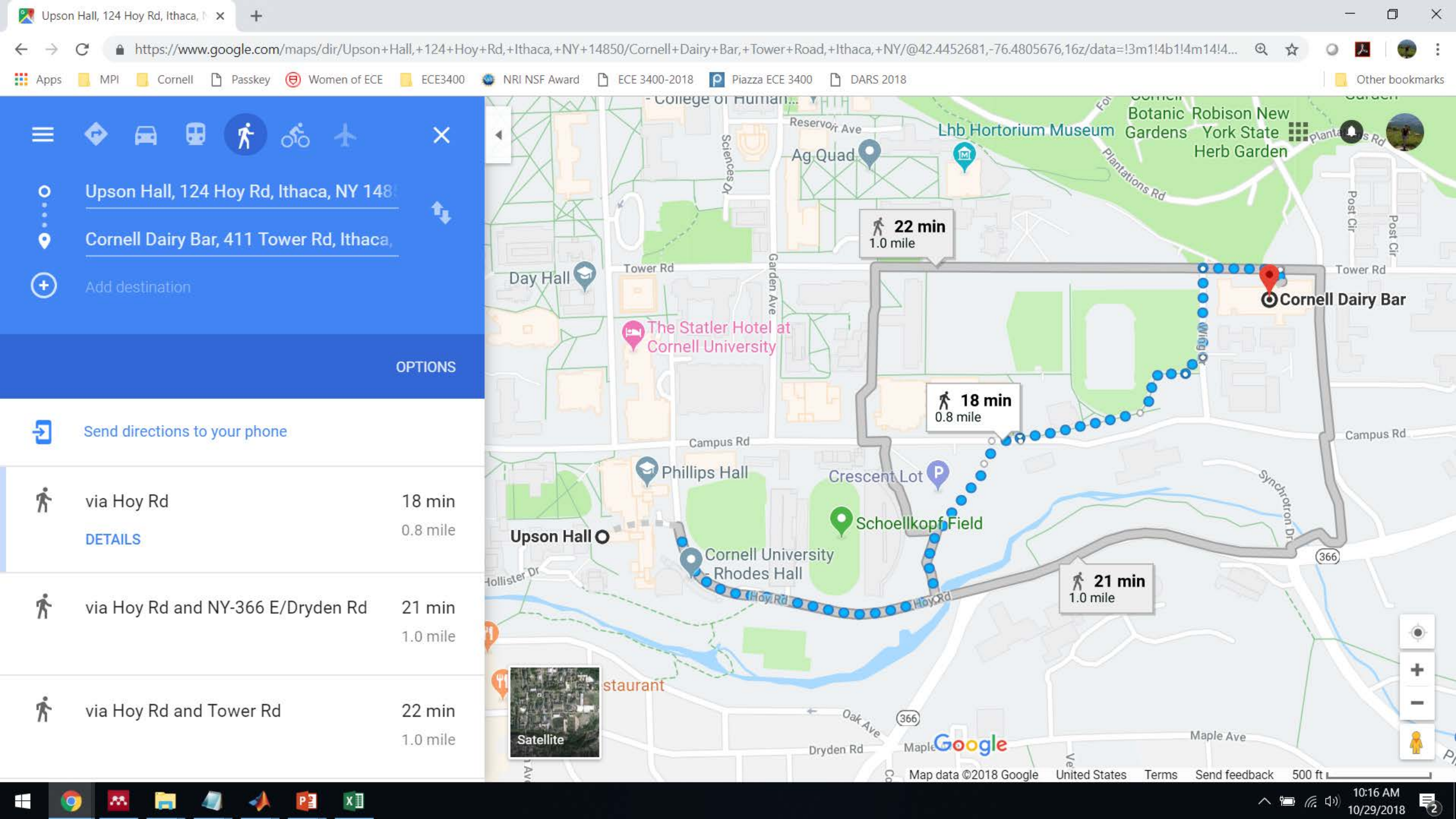


Greedy



A* *minimum path and efficient*




Upson Hall, 124 Hoy Rd, Ithaca, NY 148
Cornell Dairy Bar, 411 Tower Rd, Ithaca,
Add destination
OPTIONS
Send directions to your phone
via Hoy Rd
18 min
0.8 mile
DETAILS
via Hoy Rd and NY-366 E/Dryden Rd
21 min
1.0 mile
via Hoy Rd and Tower Rd
22 min
1.0 mile
22 min
1.0 mile
18 min
0.8 mile
21 min
1.0 mile
Upson Hall
Cornell Dairy Bar
Day Hall
The Statler Hotel at Cornell University
Phillips Hall
Crescent Lot
Schoellkopf Field
Cornell University - Rhodes Hall
Ag Quad
Lhb Hortorium Museum
Botanic Gardens
Robison New York State Herb Garden
Tower Rd
Campus Rd
Hoy Rd
Dryden Rd
Oak Ave
Maple Ave
Reservoir Ave
Plantations Rd
Garden Ave
Synchrotron Dr
Post Cir
366
Satellite
Google
Map data ©2018 Google
United States
Terms
Send feedback
500 ft

Game Theory

- Pick a whole number between 1 and 100.
- The winner is the person who picks the value which is closest to two thirds of the class average.
- E.g.
  - [10, 20, 60].
  - Class average 30.
  - Winner: 20.

- https://bit.ly/2z9R56F
- The poll will close at the end of the class (12.10pm 10/29th)

Go Build Robots!

Class website: https://cei-lab.github.io/ece3400-2018/

Piazza: https://piazza.com/cornell/fall2018/ece3400/home