A* Pseudo Code

x, y = get grid size;
Initialize valid states dictionary with f, g, h value

function initializeHeuristic:
    Create open, closed list
    Open list = goal

    Loop:
        Pick a node from open list
        Find 4-neighbors of node

        If neighbor is valid state AND is not in closed list:
            Add it to the neighbor list and closed list

        For all neighbors:
            Populate the heuristic grid (based on Manhattan or Euclidean distances)[1]
        Add neighbors to the open list, clear neighbor list
        Break if entire H grid is populated

function aStarSearch:
    Create open and closed list with start cell
    (Note: open list is of the form f, g, x, y)
    Create empty expand and action grid list

    Loop1:
        Get cell from open list with lowest ‘f’ value
        Mark the cell in expand grid
        If open list empty:
            Break as - goal not found
        else:
            If cell is goal
                Break as - goal found

            Loop2 over all actions:
                Find neighbor
                If neighbor is valid state and not in closed list:
                        Calculate f, g and h (with tie breaker)[2]
                        Add f, g, x, y of neighbor to open list and closed list
                        Add action taken to the action grid

Update f,g,h dictionary

End of Loop2

End of Loop1

 # additional steps for path coordinates #

Create a policy list with only goal cell

Loop if current cell is not start:

Find previous cell using action grid

Add previous cell to policy and make it current cell

End Loop

Notes:

[1] Manhattan or Euclidean distances

Manhattan distance of a node is the sum of horizontal and vertical distance of this node from goal node. This follows a straight path along the x and y axis if the node and goal are diagonal to each other.

Euclidean distance of a node is the square root of sum of the squares of horizontal and vertical distance from the goal node. This follows a direct diagonal path if the node and goal are diagonal to each other.

[2] Tie breaker

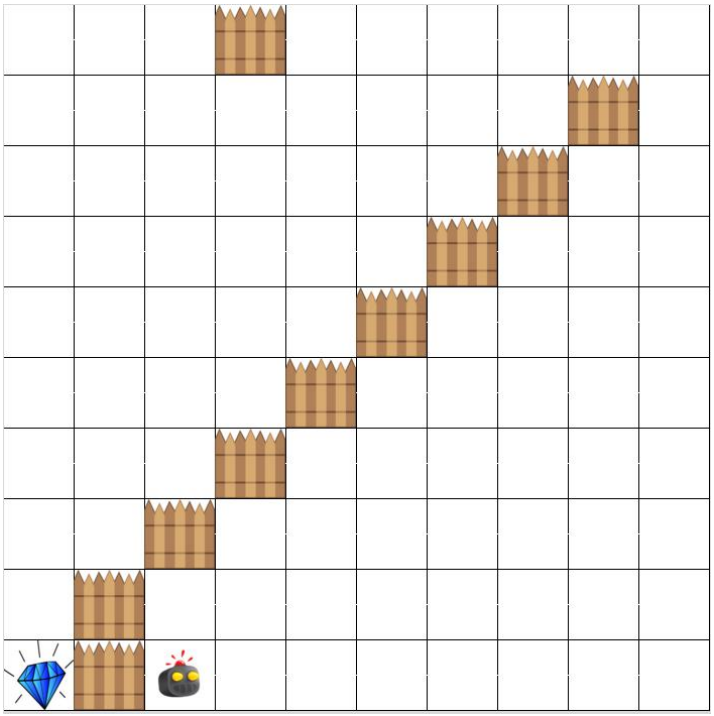
The basic heuristic grid can have multiple paths with same f values for corresponding cells and thus the A* expand towards both path. In order to expand less, we use a tie breaker scheme between both path’s h values. This is done by scaling the first picked path over the other, so that A* always first tries to follow the first path. There are different tie breaking implementations.

An *fgh* Example

Number Notations: 1/-1 = Wall; 2 = Start; 3 = Goal

Grid:

```
[ 0  0  0  1  0  0  0  0  0  0 ]
[ 0  0  0  0  0  0  0  0  1  0 ]
[ 0  0  0  0  0  0  0  1  0  0 ]
[ 0  0  0  0  0  0  1  0  0  0 ]
[ 0  0  0  0  0  1  0  0  0  0 ]
[ 0  0  0  0  1  0  0  0  0  0 ]
[ 0  0  0  1  0  0  0  0  0  0 ]
[ 0  0  1  0  0  0  0  0  0  0 ]
[ 0  1  0  0  0  0  0  0  0  0 ]
[ 3  1  2  0  0  0  0  0  0  0 ]
```



Heuristic (h)

```
[ 9 10 11 12 13 14 15 16 17 18]
[ 8  9 10 11 12 13 14 15 16 17]
[ 7  8  9 10 11 12 13 14 15 16]
[ 6  7  8  9 10 11 12 13 14 15]
[ 5  6  7  8  9 10 11 12 13 14]
[ 4  5  6  7  8  9 10 11 12 13]
[ 3  4  5  6  7  8  9 10 11 12]
[ 2  3  4  5  6  7  8  9 10 11]
[ 1  2  3  4  5  6  7  8  9 10]
[ 0  1  2  3  4  5  6  7  8  9]
```

Cost Grid (g)

```
[27 26 25  1 21 20 19 18 17 16]
[26 25 24 23 22 21 20 19 -1 15]
[27 26 25 24 23 22 21 -1 13 14]
[28 27 26 25 24 23 -1 11 12 13]
[29 28 27 26 25 -1  9 10 11 12]
[30 29 28 27 -1  7  8  9 10 11]
[31 30 29 -1  5  6  7  8  9 10]
[32 31 -1  3  4  5  6  7  8  9]
[33 -1  1  2  3  4  5  6  7  8]
[34 -1  0  1  2  3  4  5  6  7]
```

Expanded Grid with f values:
We calculate f as, f = g + h, for every expanded cell.
(Note: The yellow cells represents expanded states)

1. Using h values without a tie breaker:

				f=34.0 g=21 h=13.0	f=34.0 g=20 h=14.0	f=34.0 g=19 h=15.0	f=34.0 g=18 h=16.0	f=34.0 g=17 h=17.0	f=34.0 g=16 h=18.0
f=34.0 g=26 h=8.0	f=34.0 g=25 h=9.0	f=34.0 g=24 h=10.0	f=34.0 g=23 h=11.0	f=34.0 g=22 h=12.0	f=34.0 g=21 h=13.0	f=34.0 g=20 h=14.0	f=34.0 g=19 h=15.0		f=32.0 g=15 h=17.0
f=34.0 g=27 h=7.0	f=34.0 g=26 h=8.0	f=34.0 g=25 h=9.0	f=34.0 g=24 h=10.0	f=34.0 g=23 h=11.0	f=34.0 g=22 h=12.0	f=34.0 g=21 h=13.0		f=28.0 g=13 h=15.0	f=30.0 g=14 h=16.0
f=34.0 g=28 h=6.0	f=34.0 g=27 h=7.0	f=34.0 g=26 h=8.0	f=34.0 g=25 h=9.0	f=34.0 g=24 h=10.0	f=34.0 g=23 h=11.0		f=24.0 g=11 h=13.0	f=26.0 g=12 h=14.0	f=28.0 g=13 h=15.0
f=34.0 g=29 h=5.0	f=34.0 g=28 h=6.0	f=34.0 g=27 h=7.0	f=34.0 g=26 h=8.0	f=34.0 g=25 h=9.0		f=20.0 g=9 h=11.0	f=22.0 g=10 h=12.0	f=24.0 g=11 h=13.0	f=26.0 g=12 h=14.0
f=34.0 g=30 h=4.0	f=34.0 g=29 h=5.0	f=34.0 g=28 h=6.0	f=34.0 g=27 h=7.0		f=16.0 g=7 h=9.0	f=18.0 g=8 h=10.0	f=20.0 g=9 h=11.0	f=22.0 g=10 h=12.0	f=24.0 g=11 h=13.0
f=34.0 g=31 h=3.0	f=34.0 g=30 h=4.0	f=34.0 g=29 h=5.0		f=12.0 g=5 h=7.0	f=14.0 g=6 h=8.0	f=16.0 g=7 h=9.0	f=18.0 g=8 h=10.0	f=20.0 g=9 h=11.0	f=22.0 g=10 h=12.0
f=34.0 g=32 h=2.0	f=34.0 g=31 h=3.0		f=8.0 g=3 h=5.0	f=10.0 g=4 h=6.0	f=12.0 g=5 h=7.0	f=14.0 g=6 h=8.0	f=16.0 g=7 h=9.0	f=18.0 g=8 h=10.0	f=20.0 g=9 h=11.0
f=34.0 g=33 h=1.0		f=4.0 g=1 h=3.0	f=6.0 g=2 h=4.0	f=8.0 g=3 h=5.0	f=10.0 g=4 h=6.0	f=12.0 g=5 h=7.0	f=14.0 g=6 h=8.0	f=16.0 g=7 h=9.0	f=18.0 g=8 h=10.0
f=34.0			f=4.0 g=1 h=3.0	f=6.0 g=2 h=4.0	f=8.0 g=3 h=5.0	f=10.0 g=4 h=6.0	f=12.0 g=5 h=7.0	f=14.0 g=6 h=8.0	f=16.0 g=7 h=9.0

2. Using h values with a tie breaker:

				f=35.3 g=21 h=14.3	f=35.4 g=20 h=15.4	f=35.5 g=19 h=16.5	f=35.6 g=18 h=17.6	f=35.7 g=17 h=18.7	f=35.8 g=16 h=19.8
f=34.8 g=26 h=8.8	f=34.9 g=25 h=9.9	f=35.0 g=24 h=11.0	f=35.1 g=23 h=12.1	f=35.2 g=22 h=13.2					f=33.7 g=15 h=18.7
f=34.7 g=27 h=7.7								f=29.5 g=13 h=16.5	f=31.6 g=14 h=17.6
f=34.6 g=28 h=6.6							f=25.3 g=11 h=14.3	f=27.4 g=12 h=15.4	f=29.5 g=13 h=16.5
f=34.5 g=29 h=5.5						f=21.1 g=9 h=12.1	f=23.2 g=10 h=13.2	f=25.3 g=11 h=14.3	f=27.4 g=12 h=15.4
f=34.4 g=30 h=4.4					f=16.9 g=7 h=9.9	f=19.0 g=8 h=11.0	f=21.1 g=9 h=12.1	f=23.2 g=10 h=13.2	f=25.3 g=11 h=14.3
f=34.3 g=31 h=3.3				f=12.7 g=5 h=7.7	f=14.8 g=6 h=8.8	f=16.9 g=7 h=9.9	f=19.0 g=8 h=11.0	f=21.1 g=9 h=12.1	f=23.2 g=10 h=13.2
f=34.2 g=32 h=2.2			f=8.5 g=3 h=5.5	f=10.6 g=4 h=6.6	f=12.7 g=5 h=7.7	f=14.8 g=6 h=8.8	f=16.9 g=7 h=9.9	f=19.0 g=8 h=11.0	f=21.1 g=9 h=12.1
f=34.1 g=33 h=1.1		f=4.3 g=1 h=3.3	f=6.4 g=2 h=4.4	f=8.5 g=3 h=5.5	f=10.6 g=4 h=6.6	f=12.7 g=5 h=7.7	f=14.8 g=6 h=8.8	f=16.9 g=7 h=9.9	f=19.0 g=8 h=11.0
f=34.0 g=34 h=0.0			f=4.3 g=1 h=3.3	f=6.4 g=2 h=4.4	f=8.5 g=3 h=5.5	f=10.6 g=4 h=6.6	f=12.7 g=5 h=7.7	f=14.8 g=6 h=8.8	f=16.9 g=7 h=9.9