2. Grid-based path planning

A* path planner

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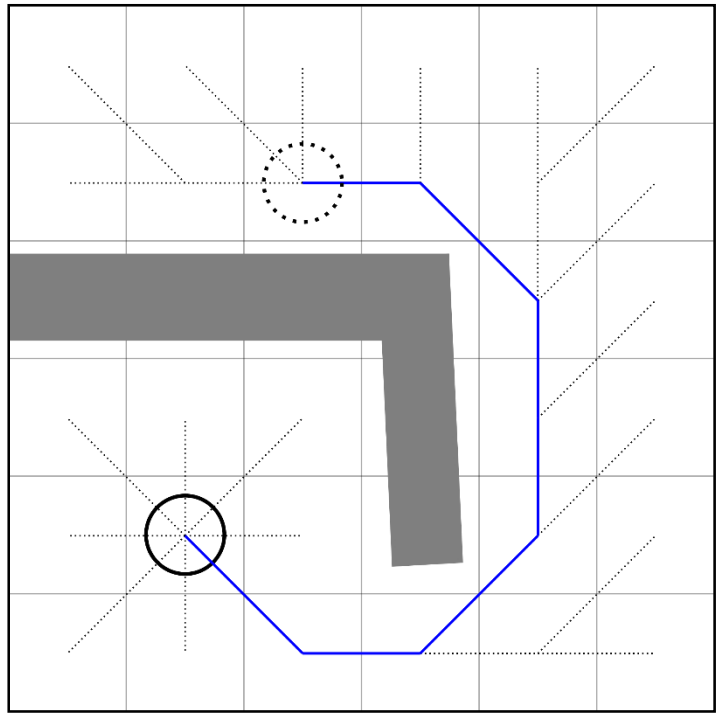
Preparation of tutorial

- **Checking your system for this tutorial**

ROS Melodic	https://www.ros.org/	
SuperRay library	https://github.com/PinocchioYS/SuperRay	Mapping and collision detection in 2-D
Clion	https://www.jetbrains.com/ko-kr/clion/	IDE for C++
Tutorial sources	https://github.com/PinocchioYS/path_planning_tutorial	

Grid-based path planning: A*

- **How to find the collision free path toward the goal**



Grid-based planner
A* planning

Input: start & goal configurations; **Output**: collision free path

```
1   open set inserts start node
2   while open set is not empty
3       current ← a configuration having the lowest F in open set
4       if current ≡ goal then
5           return collision free path
6       closed set inserts current
7       for each neighbor of current
8           new G ← G of current + visited cost from current to neighbor
9           if new G < G of neighbor
10              G of neighbor ← new G
11              H of neighbor ← heuristic cost from current to goal
12              parent of neighbor ← current
13      end for
14  end while
```

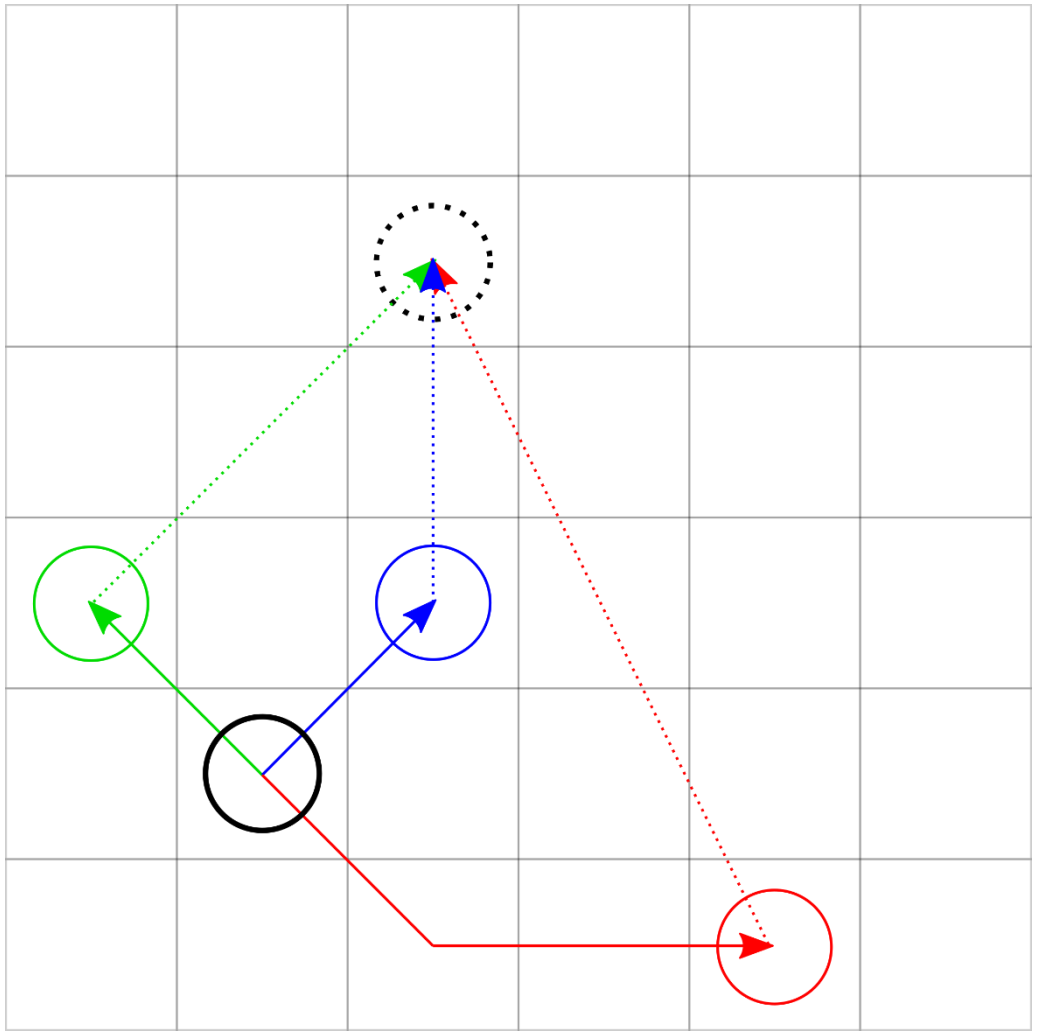
Grid-based path planning: A*

- **Definition of COSTs**

Visited cost	Heuristic cost
G cost	H cost
A real cost for visiting **a node** from the **start node**	A expectation cost to reach the **goal node** from **a node**
	G(a, goal) ≥ H(a, goal)

Node	G (solid line)	H (dotted line)	F = G + H
red	2.00+1.41	4.47	7.88
blue	1.41	2.00	3.41
green	1.41	2.82	4.23

This example uses Euclidean distance as heuristic cost.

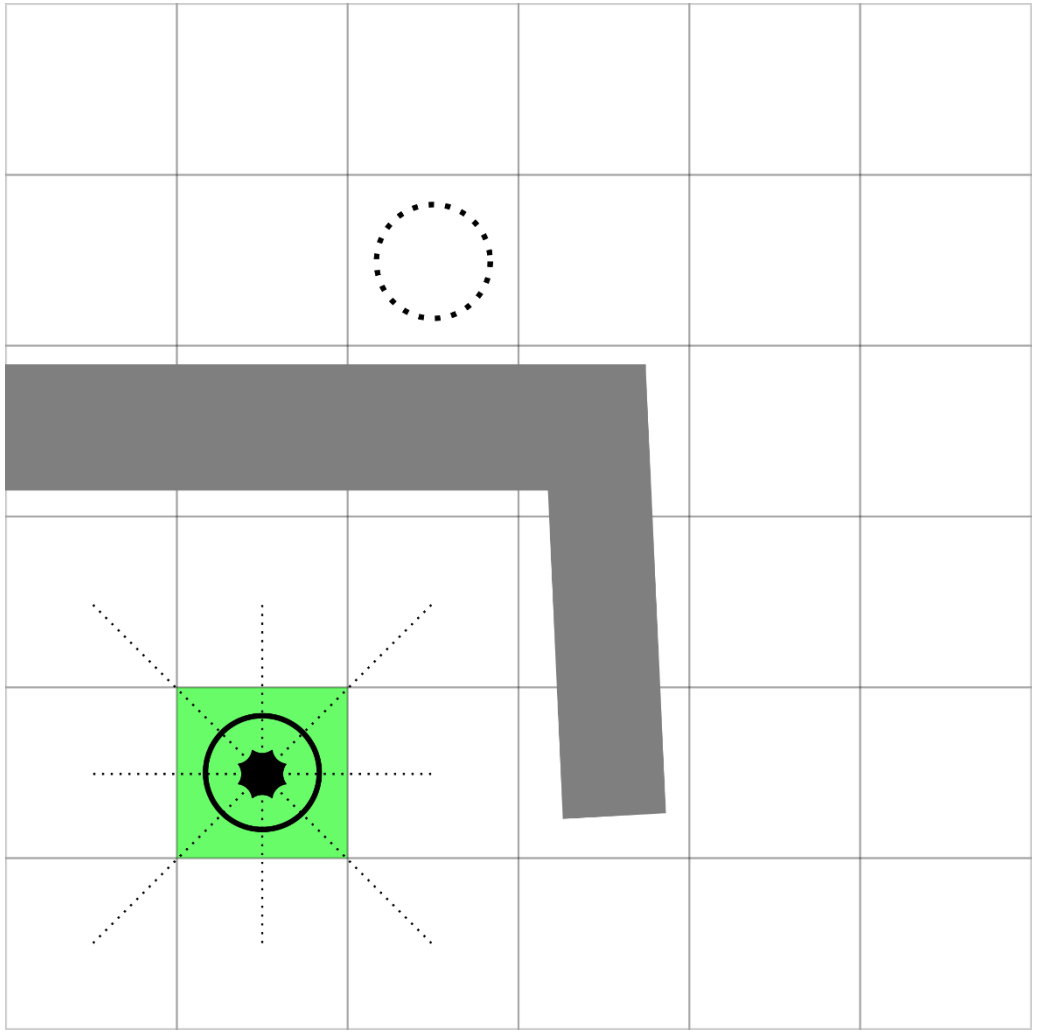


Grid-based path planning: A*

Open set:
nodes that are not visited

4.24 g: 1.41 h: 2.83	**3.24** g: 1.00 h: 2.24	**3.41** g: 1.41 h: 2.00
4.61 g: 1.00 h: 3.61	**3.16** **g: 0.00** **h: 3.16**	**4.00** g: 1.00 h: 3.00
5.88 g: 1.41 h: 4.47	**5.12** g: 1.00 h: 4.12	**5.41** g: 1.41 h: 4.00

Closed set:
visited nodes



Grid-based path planning: A*

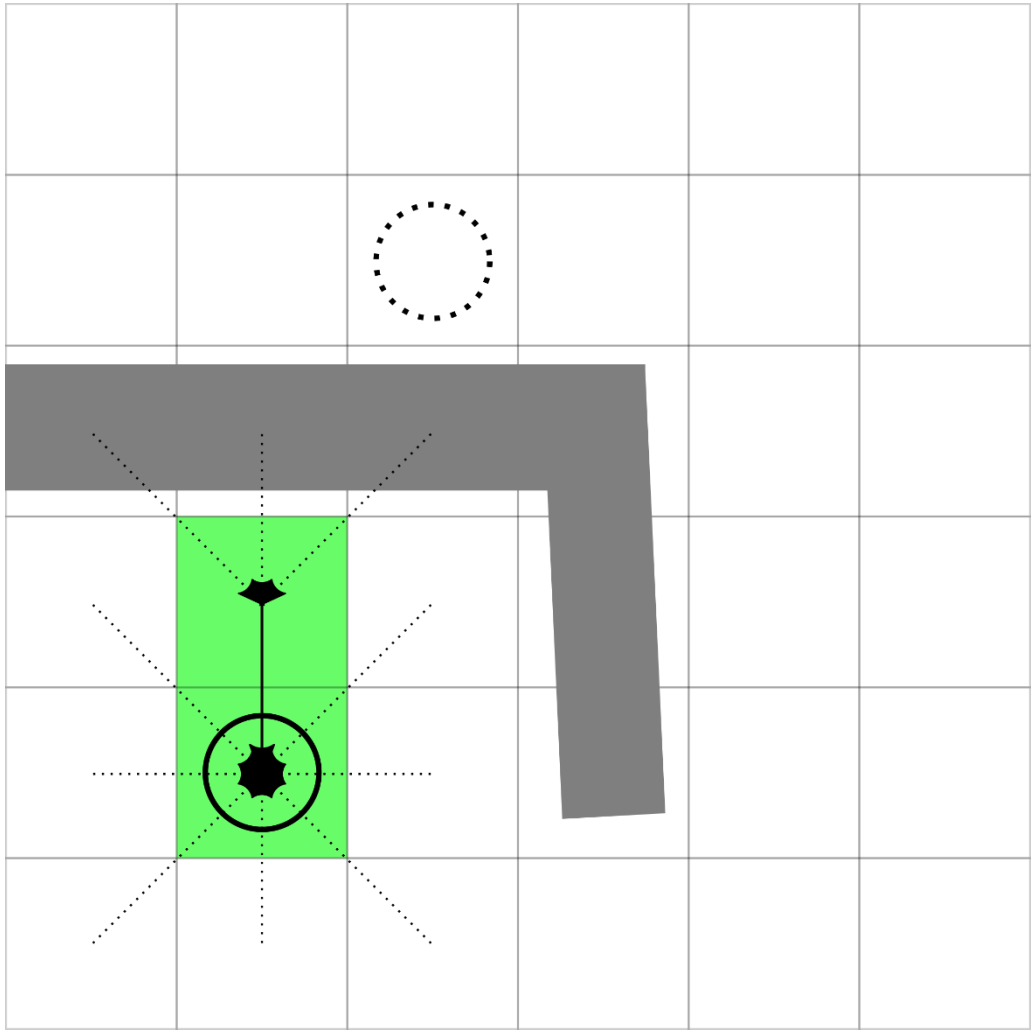
Visit the node having the lowest F cost in open set!

The lowest F cost
= the highest chance to reach the goal
through the optimal path

4.65 g: 2.41 h: 2.24	**3.41** g: 2.00 h: 1.41	**3.41** g: 2.41 h: 1.00
4.24 g: 1.41 h: 2.83	**3.24** g: 1.00 h: 2.24	**3.41** g: 1.41 h: 2.00
4.61 g: 1.00 h: 3.61	**3.16** g: 0.00 h: 3.16	**4.00** g: 1.00 h: 3.00
5.88 g: 1.41 h: 4.47	**5.12** g: 1.00 h: 4.12	**5.41** g: 1.41 h: 4.00

3.16 g: **0.00** h: 3.16	vs.	**3.24** g: 1.00 h: 2.24
		5.16 g: **2.00** h: 3.16

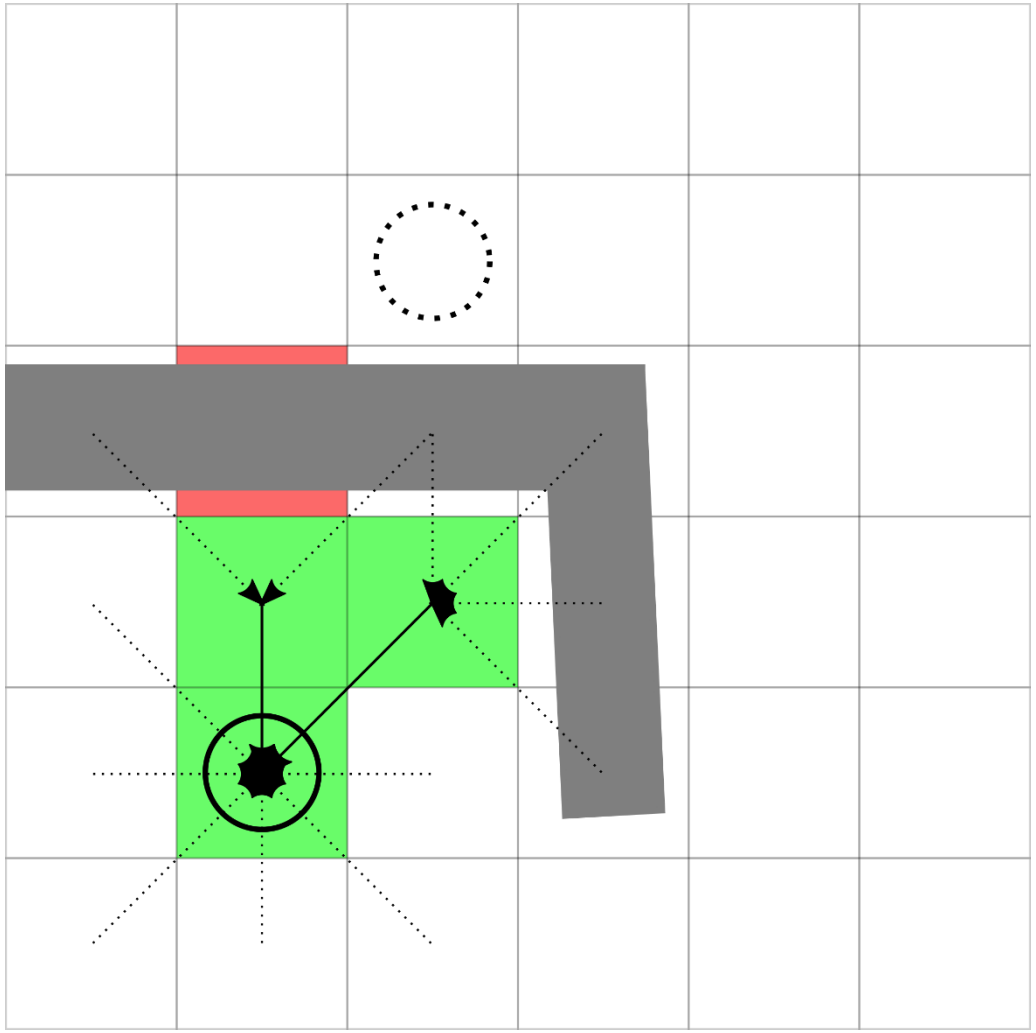
Don't insert a new node to open set.



Grid-based path planning: A*

Collision at the node (configuration)
→ don't insert the neighbors to open set
= stop to propagate the path through the node

4.65 g: 2.41 h: 2.24	**3.41**	**3.41** g: 2.41 h: 1.00	**4.23** g: 2.82 h: 1.41
4.24 g: 1.41 h: 2.83	**3.24** g: 1.00 h: 2.24	**3.41** g: 1.41 h: 2.00	**4.65** g: 2.41 h: 2.24
4.61 g: 1.00 h: 3.61	**3.16** g: 0.00 h: 3.16	**4.00** g: 1.00 h: 3.00	**5.98** g: 2.82 h: 3.16
5.88 g: 1.41 h: 4.47	**5.12** g: 1.00 h: 4.12	**5.41** g: 1.41 h: 4.00	



Grid-based path planning: A*

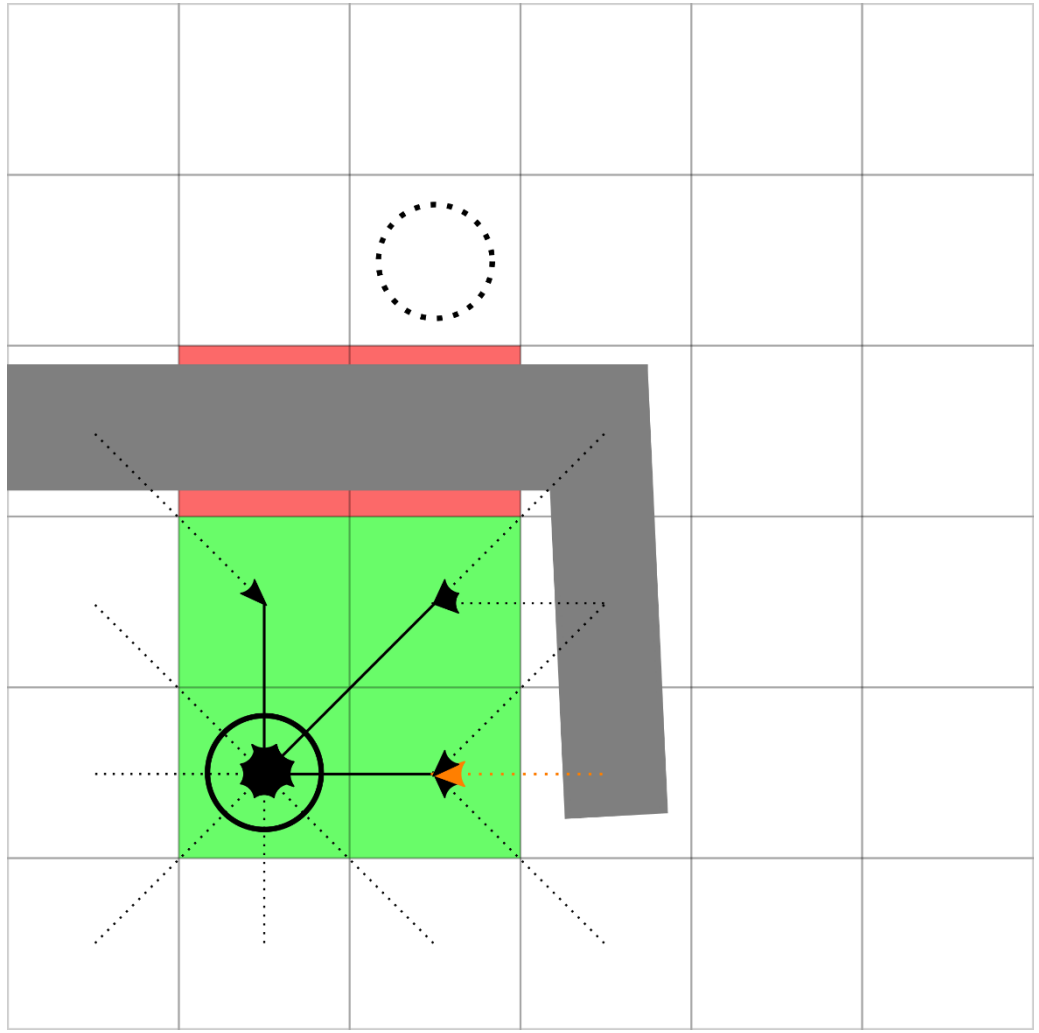
3.41 g: 1.41 h: 2.00	
	5.98 g: **2.82** h: 3.16

vs.

4.00 g: 1.00 h: 3.00	**5.16** g: **2.00** h: 3.16

4.65 g: 2.41 h: 2.24	**3.41**	**3.41**	**4.23** g: 2.82 h: 1.41
4.24 g: 1.41 h: 2.83	**3.24** g: 1.00 h: 2.24	**3.41** g: 1.41 h: 2.00	**4.65** g: 2.41 h: 2.24
4.61 g: 1.00 h: 3.61	**3.16** g: 0.00 h: 3.16	**4.00** g: 1.00 h: 3.00	**5.16** g: 2.00 h: 3.16
5.88 g: 1.41 h: 4.47	**5.12** g: 1.00 h: 4.12	**5.41** g: 1.41 h: 4.00	**6.53** g: 2.41 h: 4.12

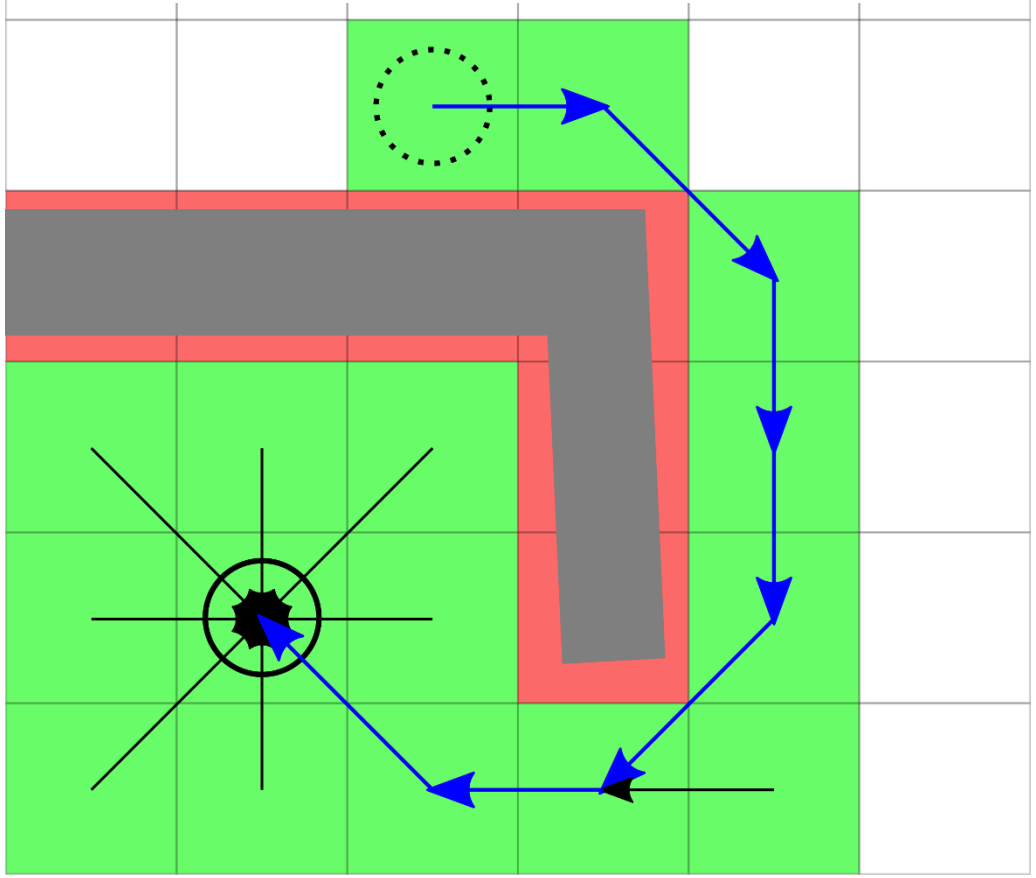
Update the G cost and the link of the neighbor



Grid-based path planning: A*

		9.64 g: 8.64 h: 1.00	**9.64** g: 8.23 h: 1.41	**10.88** g: 8.64 h: 2.24	
		8.23 g: 8.23 h: 0.00	**8.23** g: 7.23 h: 1.00	**8.82** g: 6.82 h: 2.00	**10.23** g: 7.23 h: 3.00
4.65	**3.41**	**3.41**	**4.23**	**8.06** g: 5.82 h: 2.24	**9.39** g: 6.23 h: 3.16
4.24 g: 1.41 h: 2.83	**3.24** g: 1.00 h: 2.24	**3.41** g: 1.41 h: 2.00	**4.65**	**7.65** g: 4.82 h: 2.83	**8.84** g: 5.23 h: 3.61
4.61 g: 1.00 h: 3.61	**3.16** g: 0.00 h: 3.16	**4.00** g: 1.00 h: 3.00	**5.16**	**7.43** g: 3.82 h: 3.61	**9.06** g: 4.82 h: 4.24
5.88 g: 1.41 h: 4.47	**5.12** g: 1.00 h: 4.12	**5.41** g: 1.41 h: 4.00	**6.53** g: 2.41 h: 4.12	**7.88** g: 3.41 h: 4.47	**9.41** g: 4.41 h: 5.00

Find a collision free path by visiting the nodes from goal to start through their links.



Q&A

Thank you for listening

Appendix: example of A* planning

4.24 g: 1.41 h: 2.83	**3.24** g: 1.00 h: 2.24	**3.41** g: 1.41 h: 2.00			
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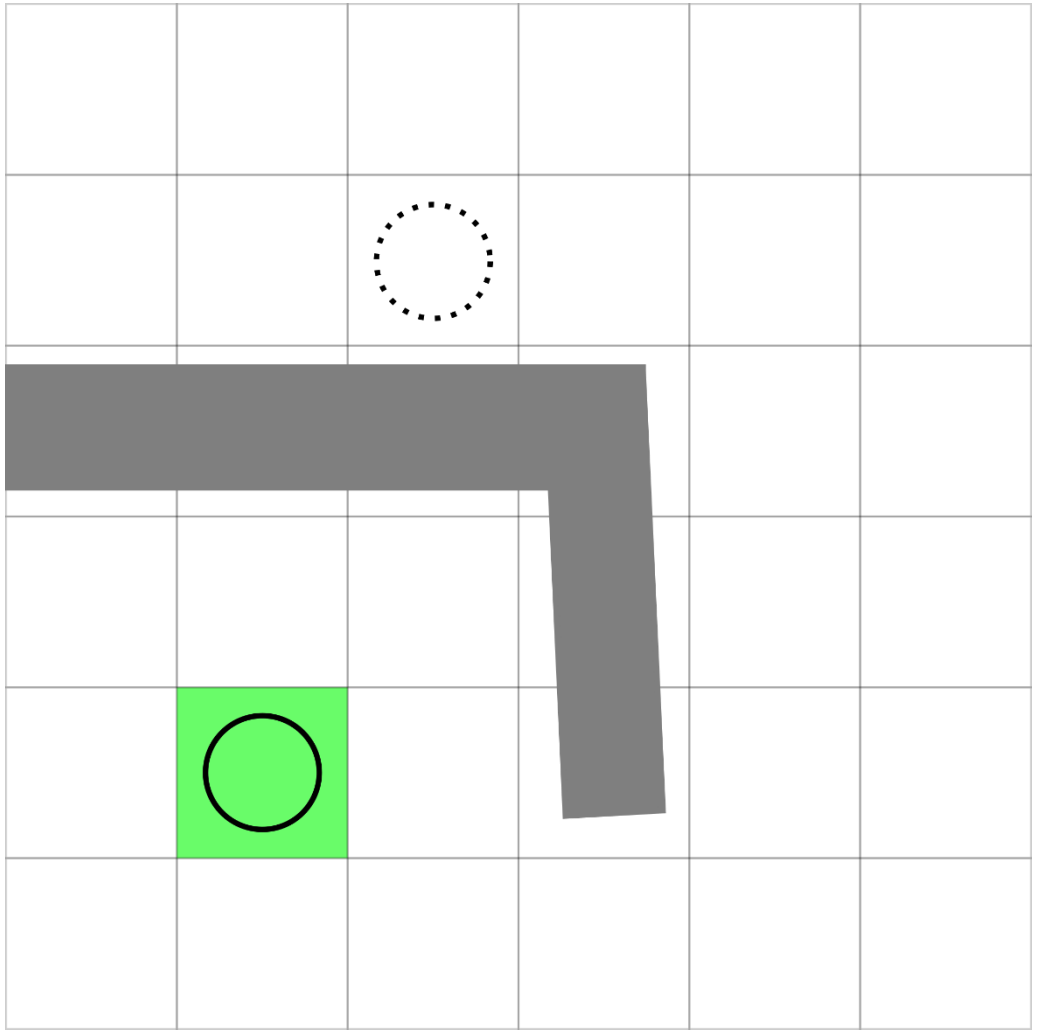

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4.24 g: 1.41 h: 2.83	**3.24** g: 1.00 h: 2.24	**3.41** g: 1.41 h: 2.00			
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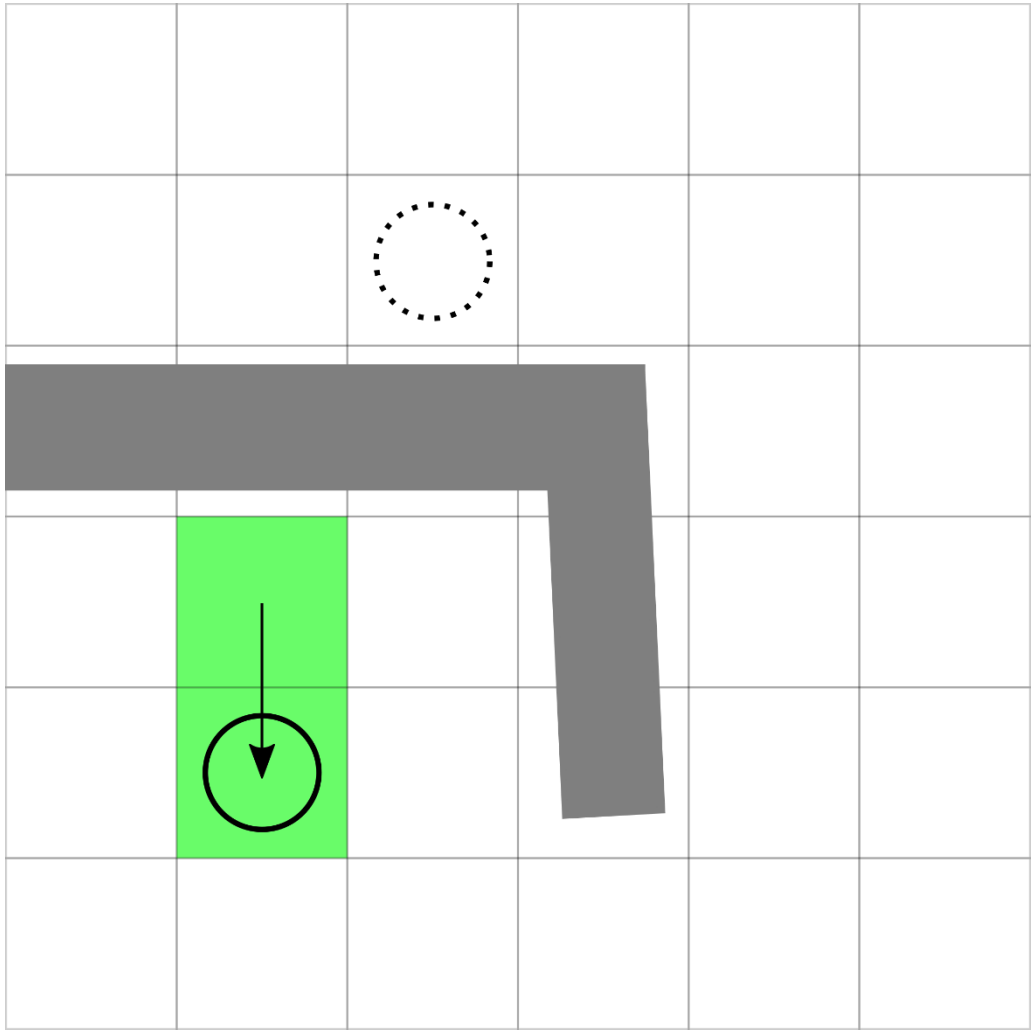
5.88 g: 1.41 h: 4.47	**5.12** g: 1.00 h: 4.12	**5.41** g: 1.41 h: 4.00			



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4.24 g: 1.41 h: 2.83	**3.24** g: 1.00 h: 2.24	**3.41** g: 1.41 h: 2.00	**4.65** g: 2.41 h: 2.24		
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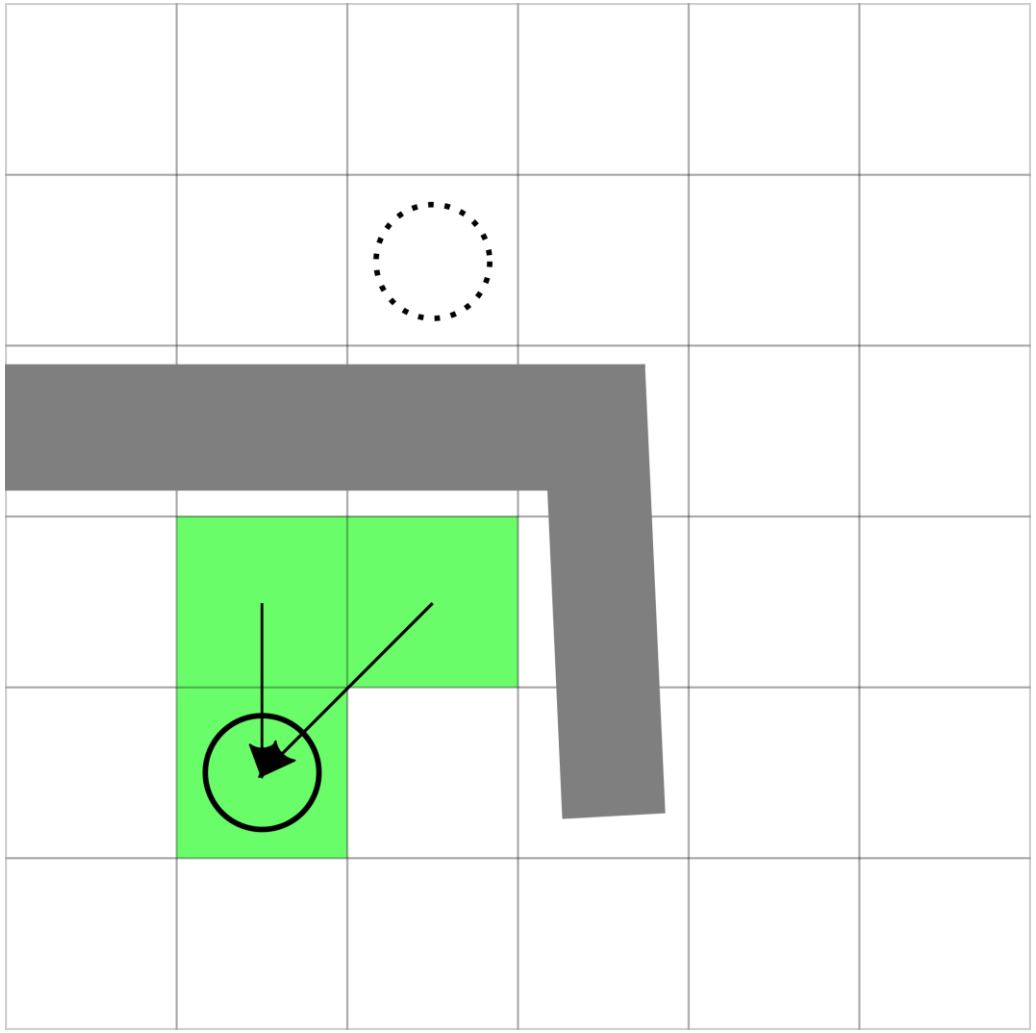

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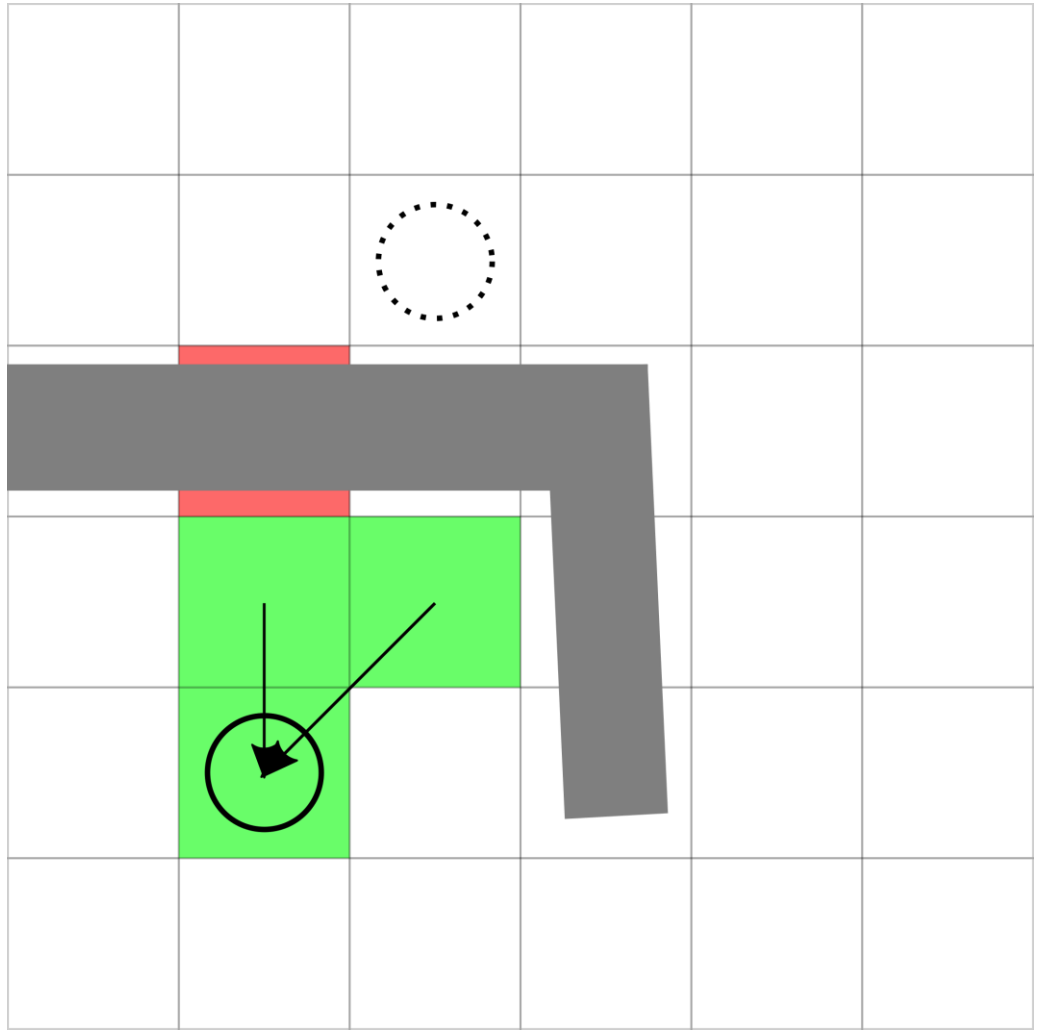

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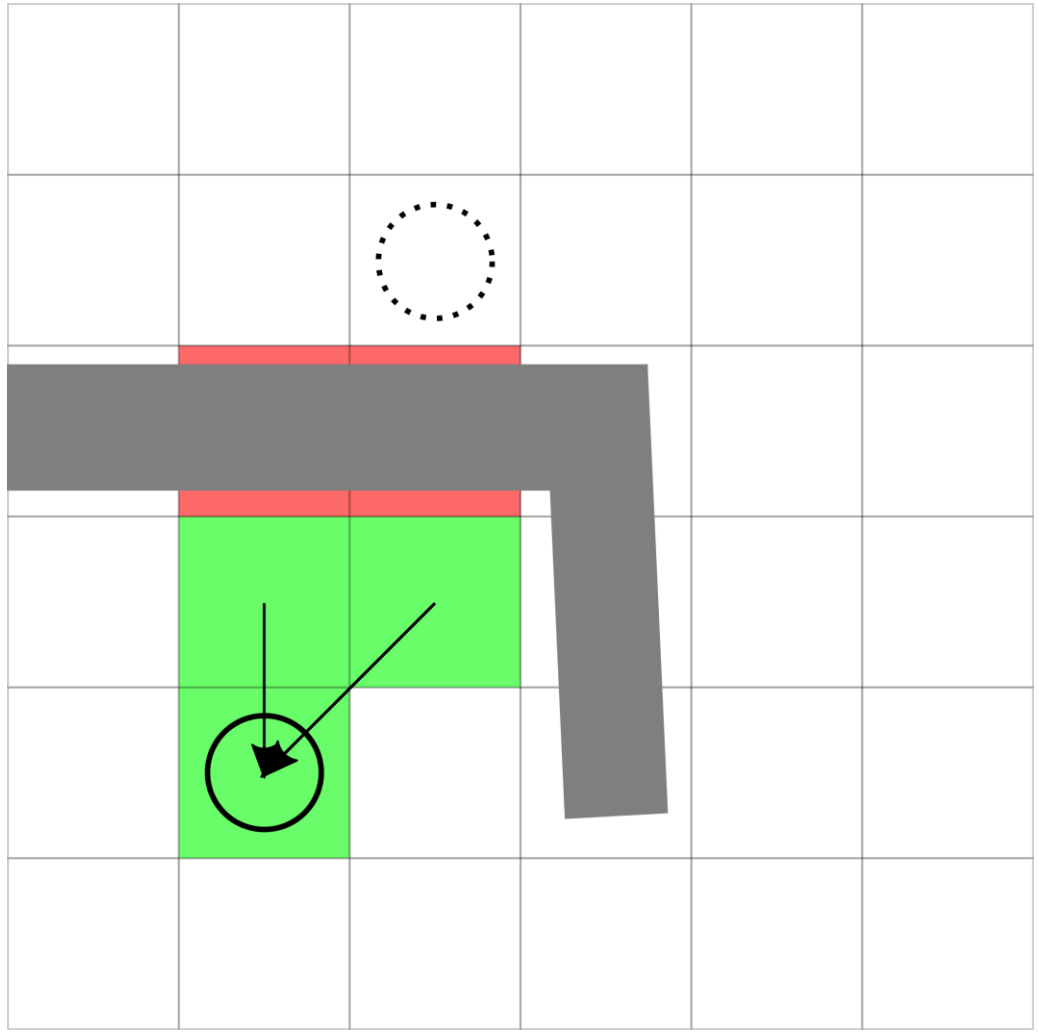

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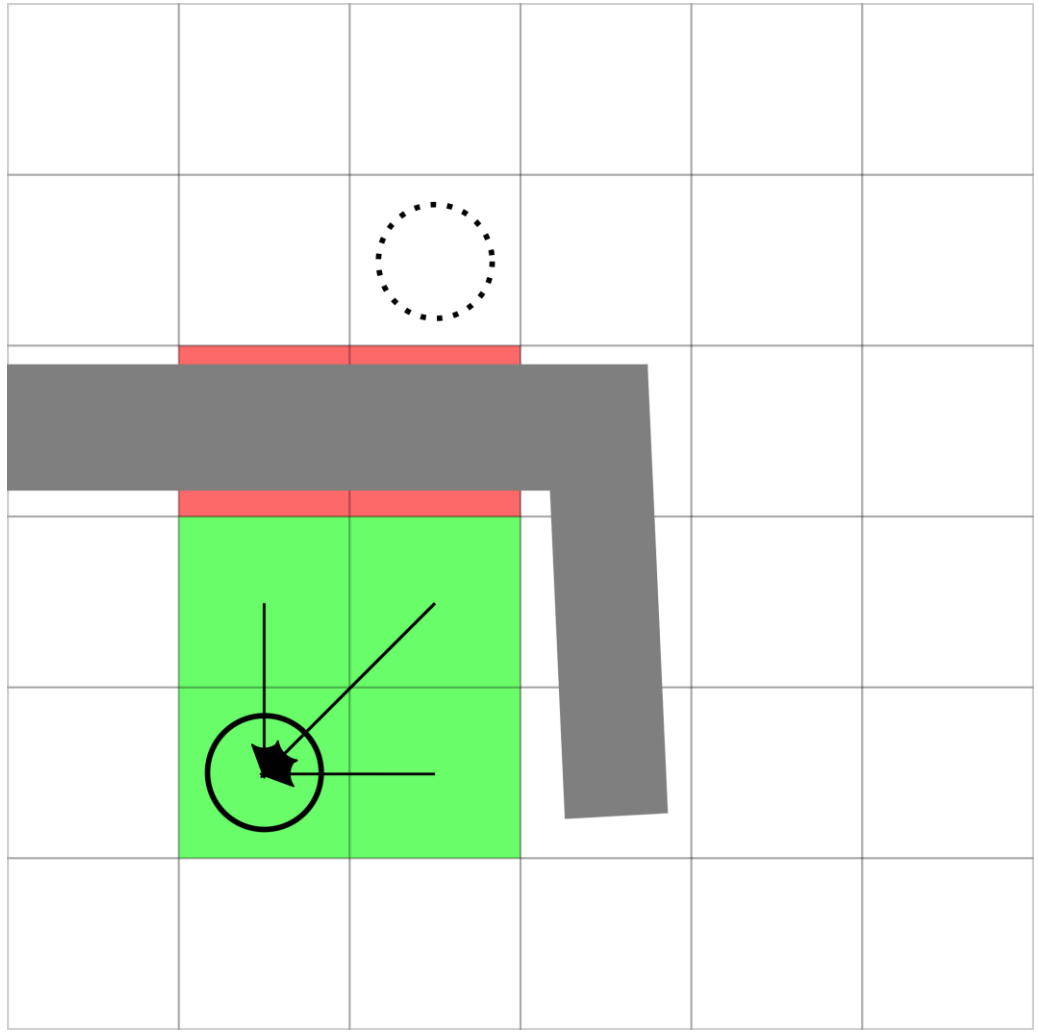

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4.24 g: 1.41 h: 2.83	**3.24** g: 1.00 h: 2.24	**3.41** g: 1.41 h: 2.00	**4.65** g: 2.41 h: 2.24		
4.61 g: 1.00 h: 3.61	**3.16** g: 0.00 h: 3.16	**4.00** g: 1.00 h: 3.00	**5.16** g: 2.00 h: 3.16		
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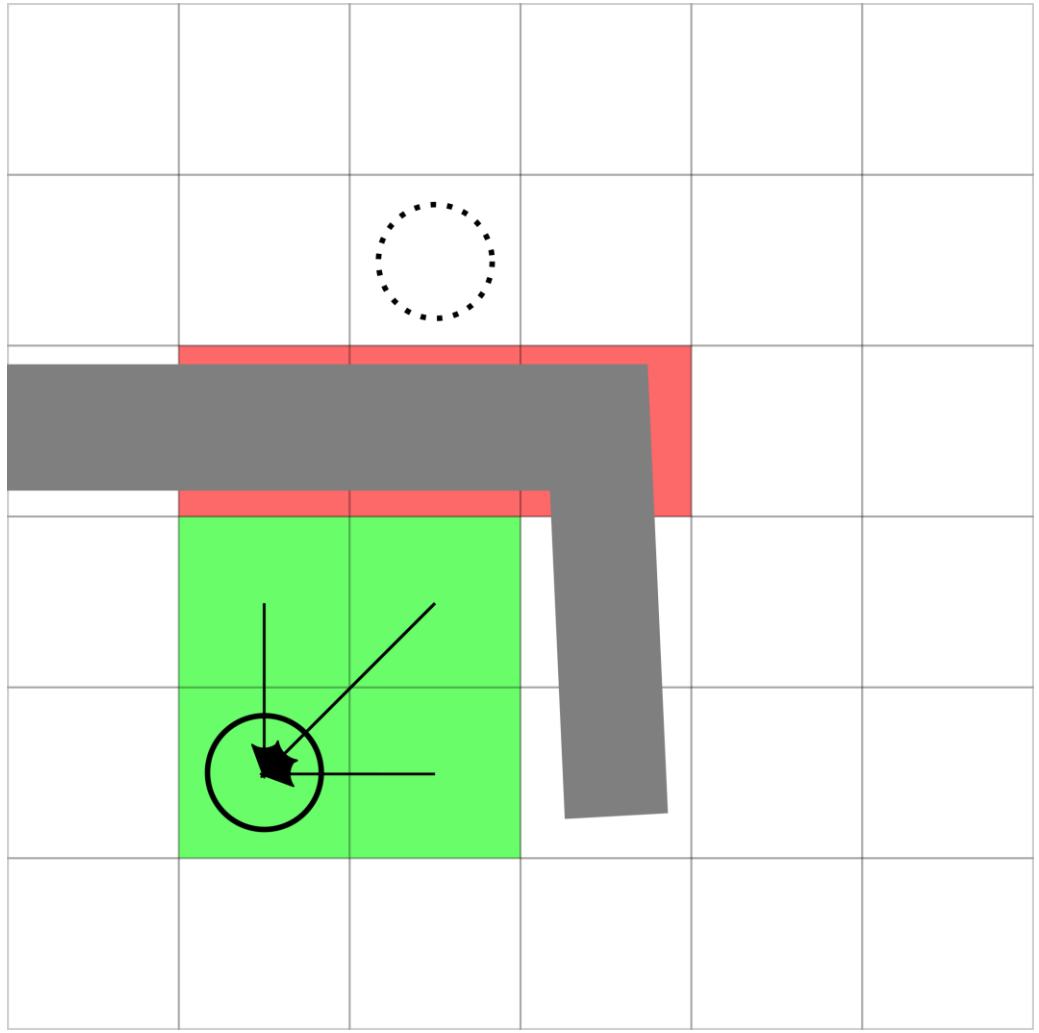

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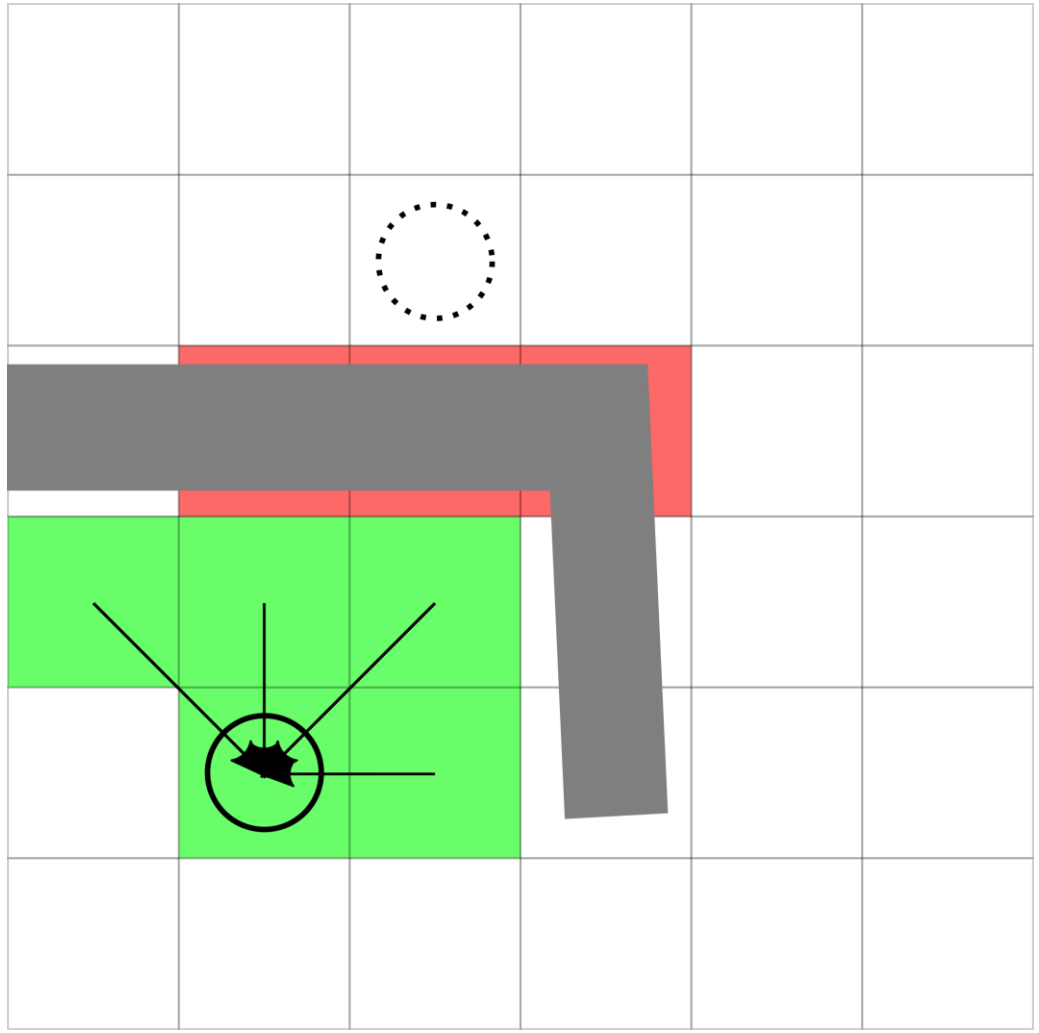

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4.24 g: 1.41 h: 2.83	**3.24** g: 1.00 h: 2.24	**3.41** g: 1.41 h: 2.00	**4.65** g: 2.41 h: 2.24		
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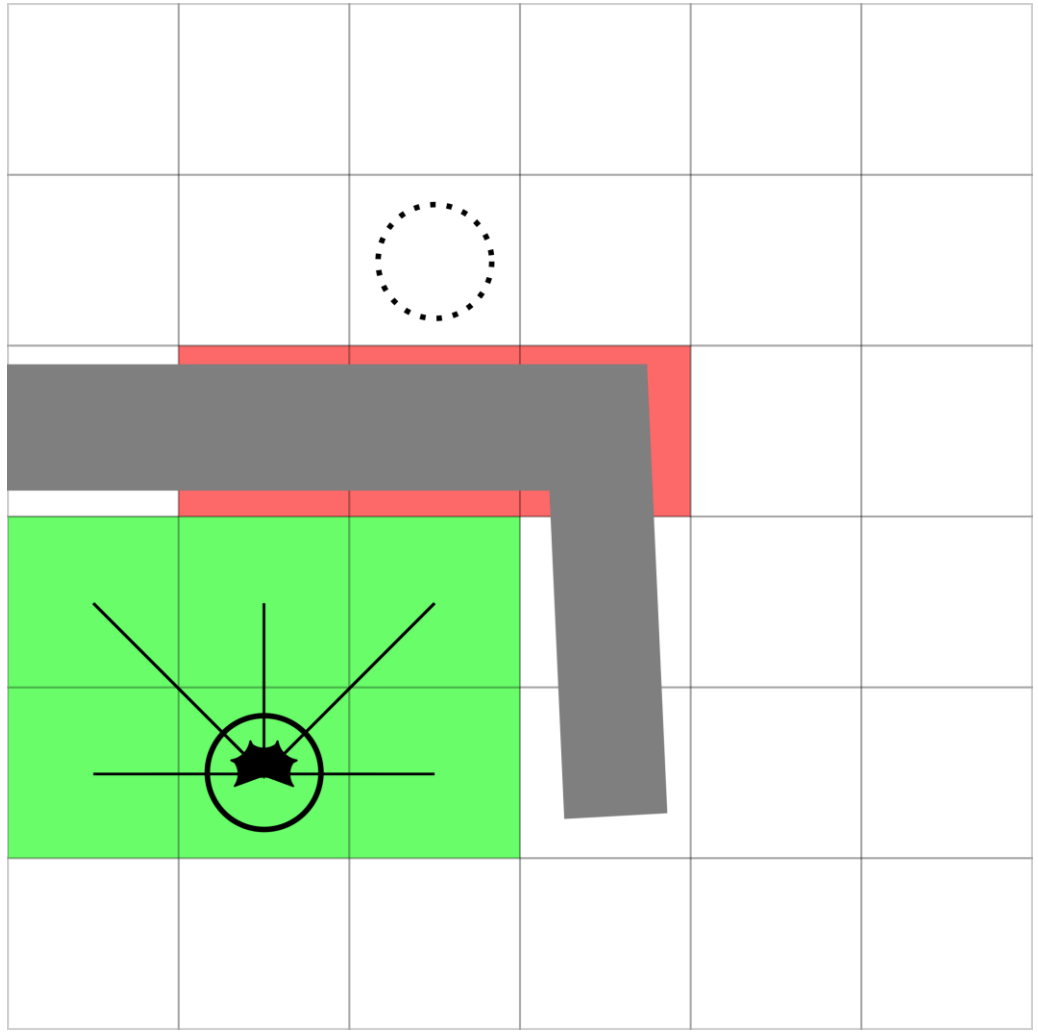

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4.65	**3.41**	**3.41**	**4.23**		
4.24 g: 1.41 h: 2.83	**3.24** g: 1.00 h: 2.24	**3.41** g: 1.41 h: 2.00	**4.65** g: 2.41 h: 2.24		
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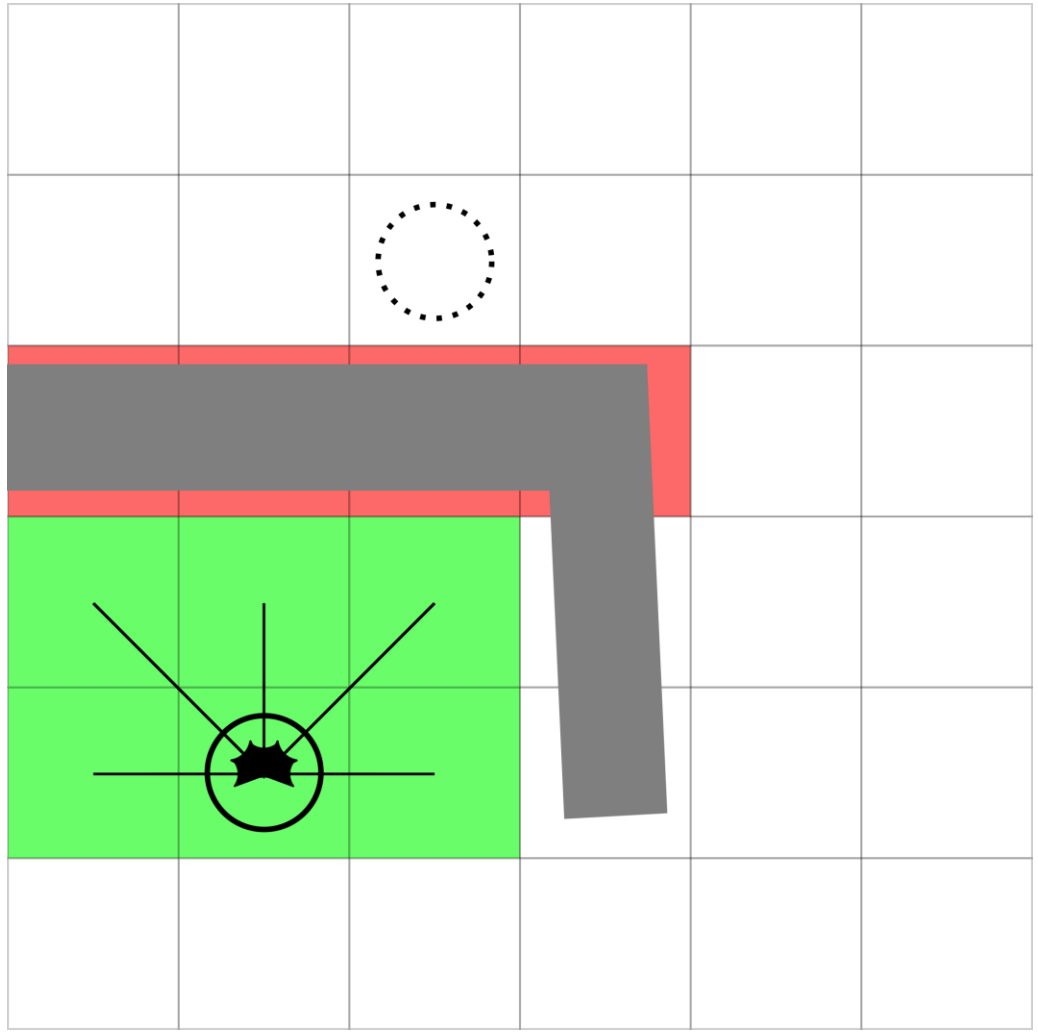

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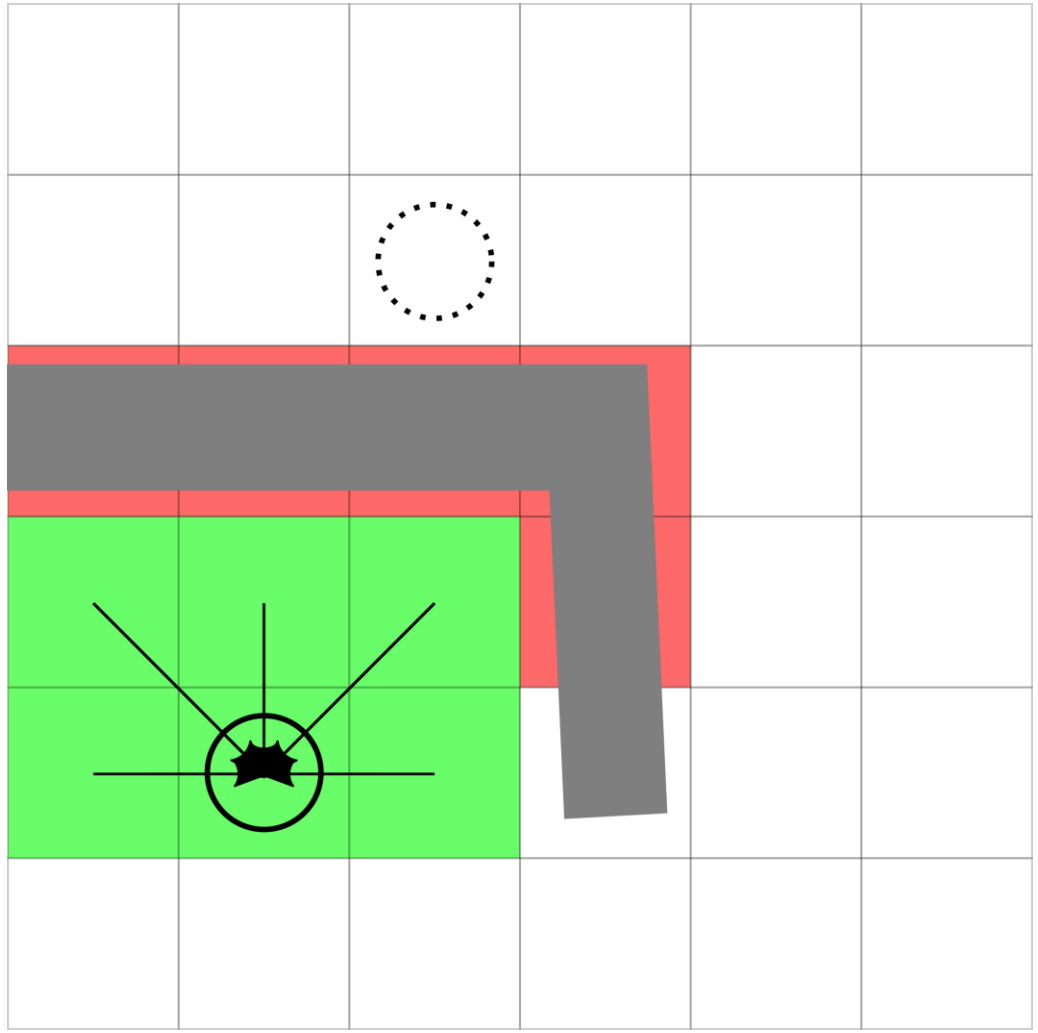

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4.65	**3.41**	**3.41**	**4.23**		
4.24 g: 1.41 h: 2.83	**3.24** g: 1.00 h: 2.24	**3.41** g: 1.41 h: 2.00	**4.65**		
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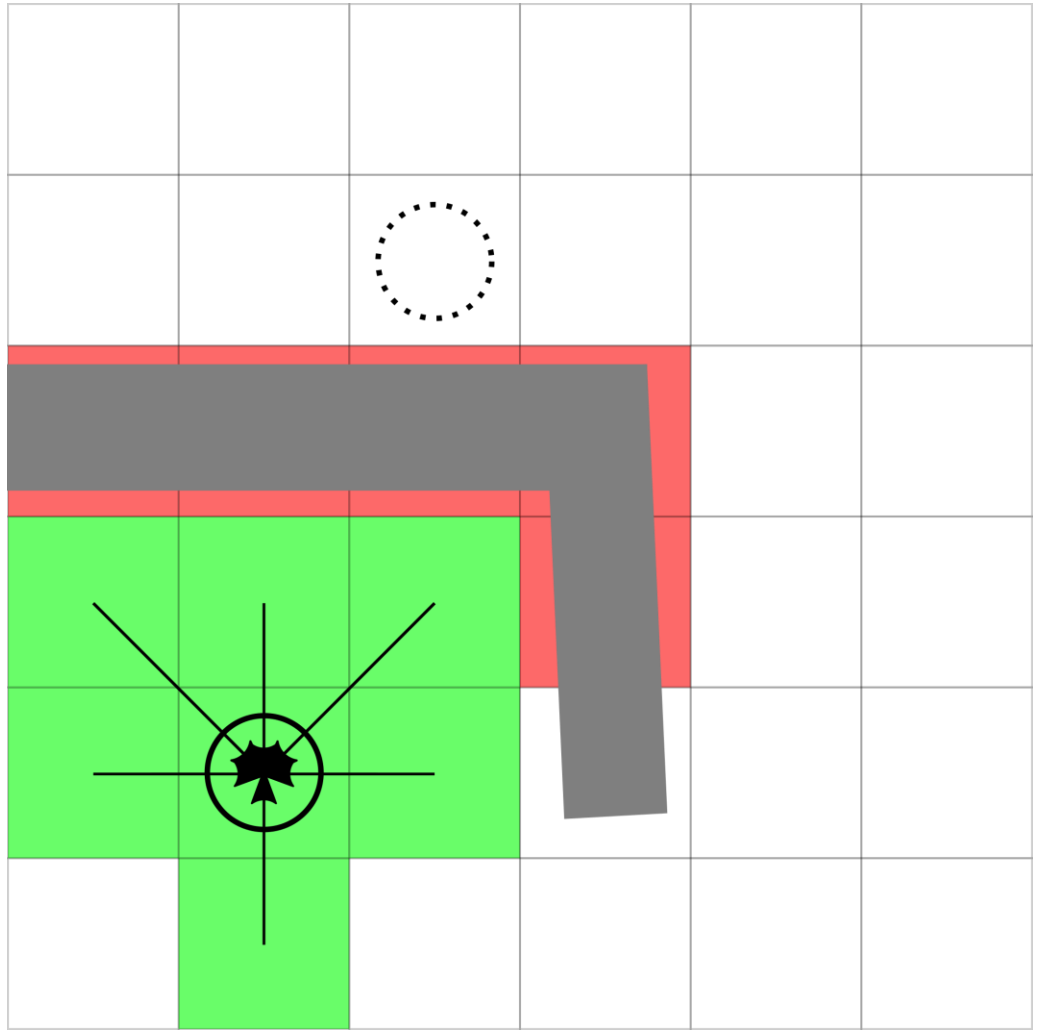

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4.24 g: 1.41 h: 2.83	**3.24** g: 1.00 h: 2.24	**3.41** g: 1.41 h: 2.00	**4.65**		
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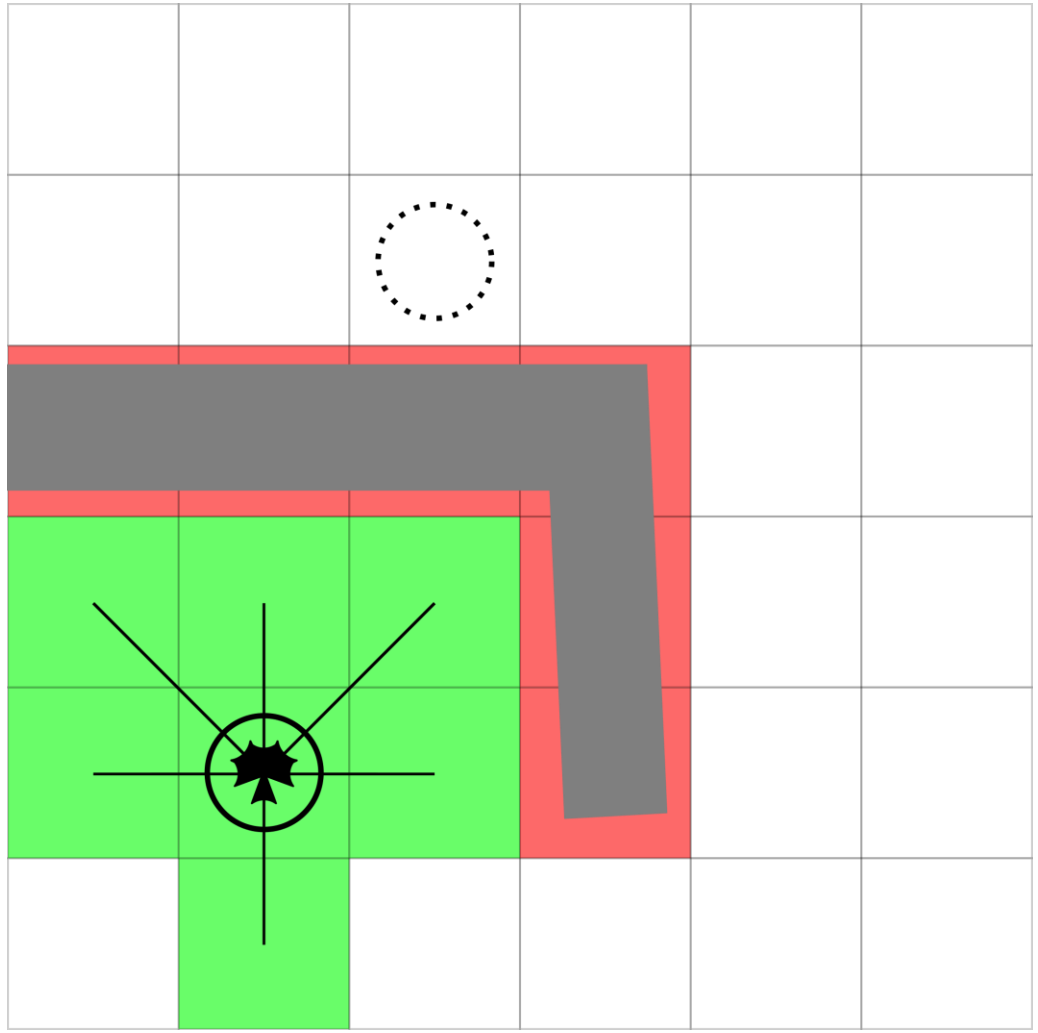

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4.24 g: 1.41 h: 2.83	**3.24** g: 1.00 h: 2.24	**3.41** g: 1.41 h: 2.00	**4.65**		
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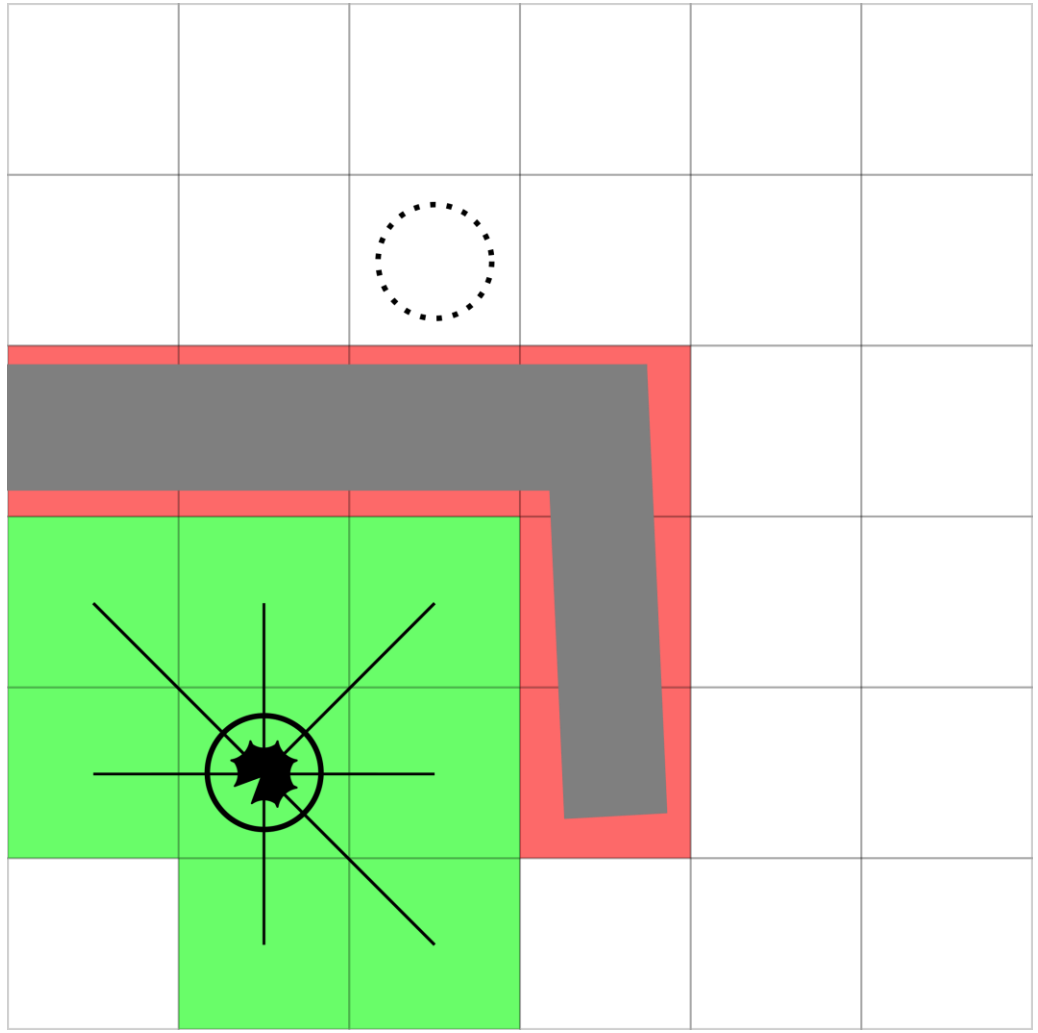
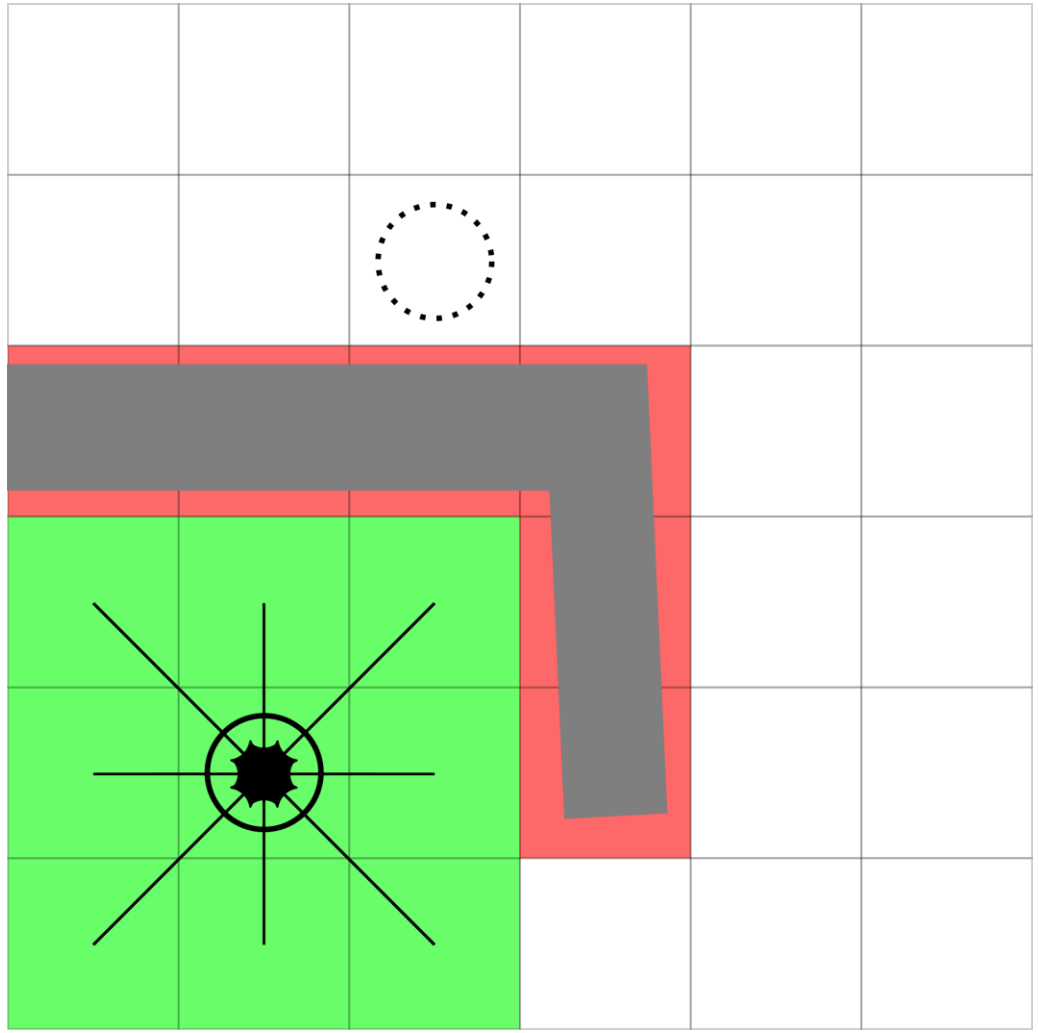


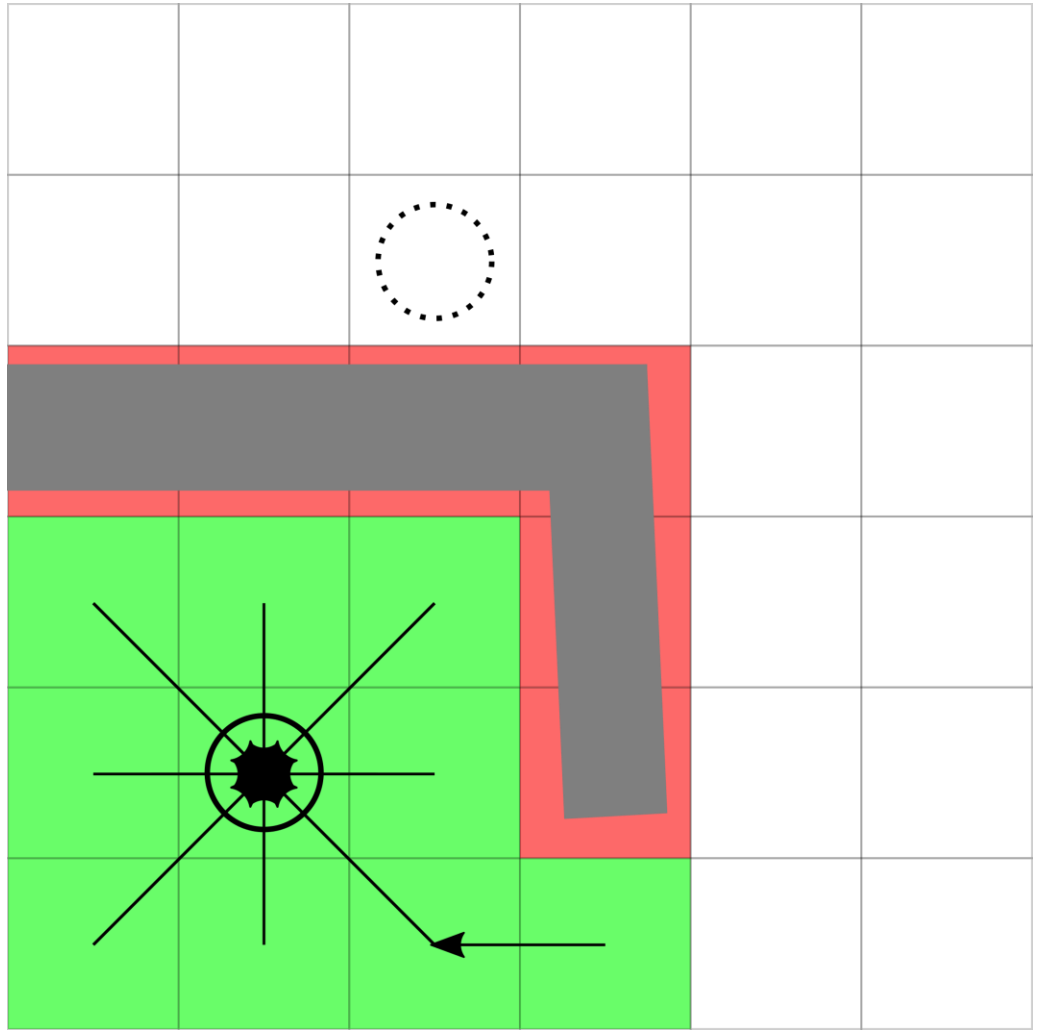
Appendix: example of A* planning

4.65	**3.41**	**3.41**	**4.23**		
4.24 g: 1.41 h: 2.83	**3.24** g: 1.00 h: 2.24	**3.41** g: 1.41 h: 2.00	**4.65**		
4.61 g: 1.00 h: 3.61	**3.16** g: 0.00 h: 3.16	**4.00** g: 1.00 h: 3.00	**5.16**		
5.88 g: 1.41 h: 4.47	**5.12** g: 1.00 h: 4.12	**5.41** g: 1.41 h: 4.00	**6.53** g: 2.41 h: 4.12		



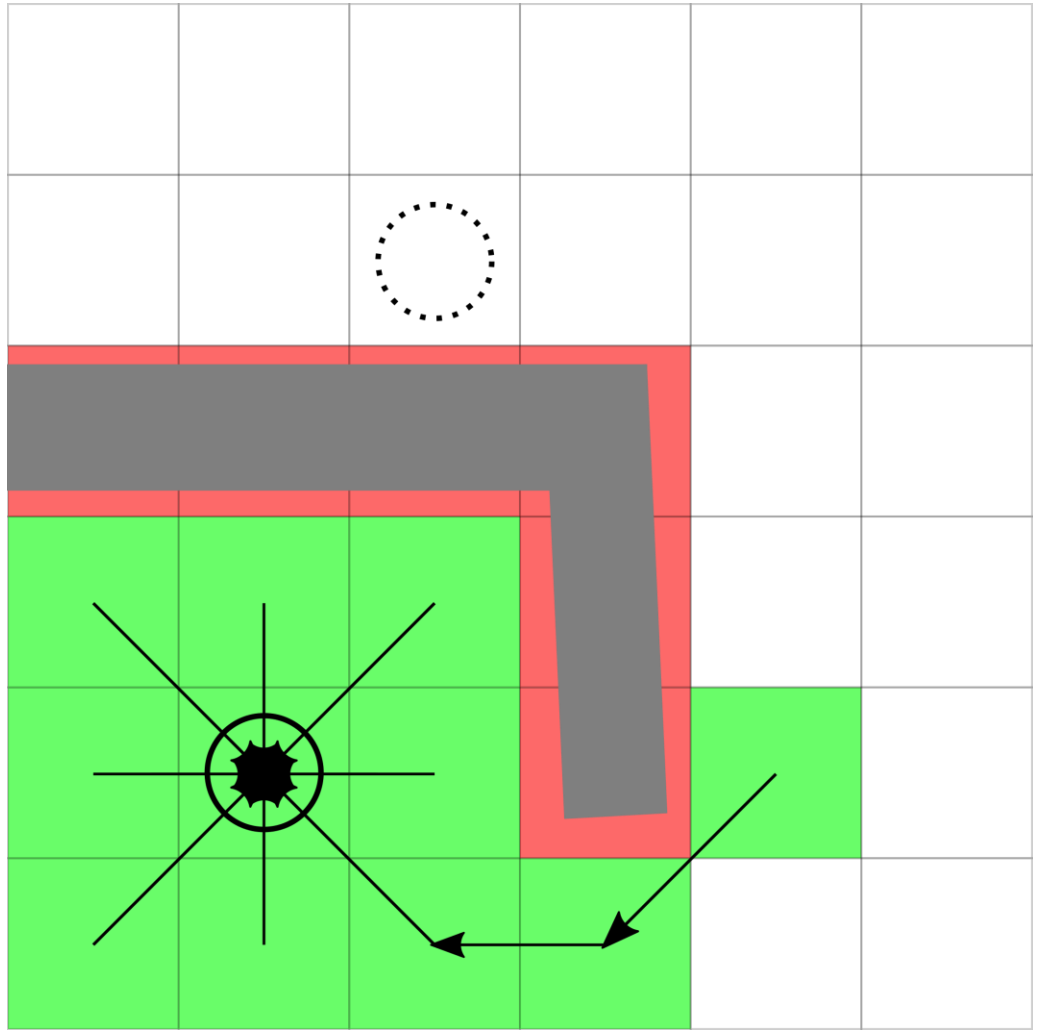
Appendix: example of A* planning

4.65	**3.41**	**3.41**	**4.23**		
4.24 g: 1.41 h: 2.83	**3.24** g: 1.00 h: 2.24	**3.41** g: 1.41 h: 2.00	**4.65**		
4.61 g: 1.00 h: 3.61	**3.16** g: 0.00 h: 3.16	**4.00** g: 1.00 h: 3.00	**5.16**	**7.43** g: 3.82 h: 3.61	
5.88 g: 1.41 h: 4.47	**5.12** g: 1.00 h: 4.12	**5.41** g: 1.41 h: 4.00	**6.53** g: 2.41 h: 4.12	**7.88** g: 3.41 h: 4.47	



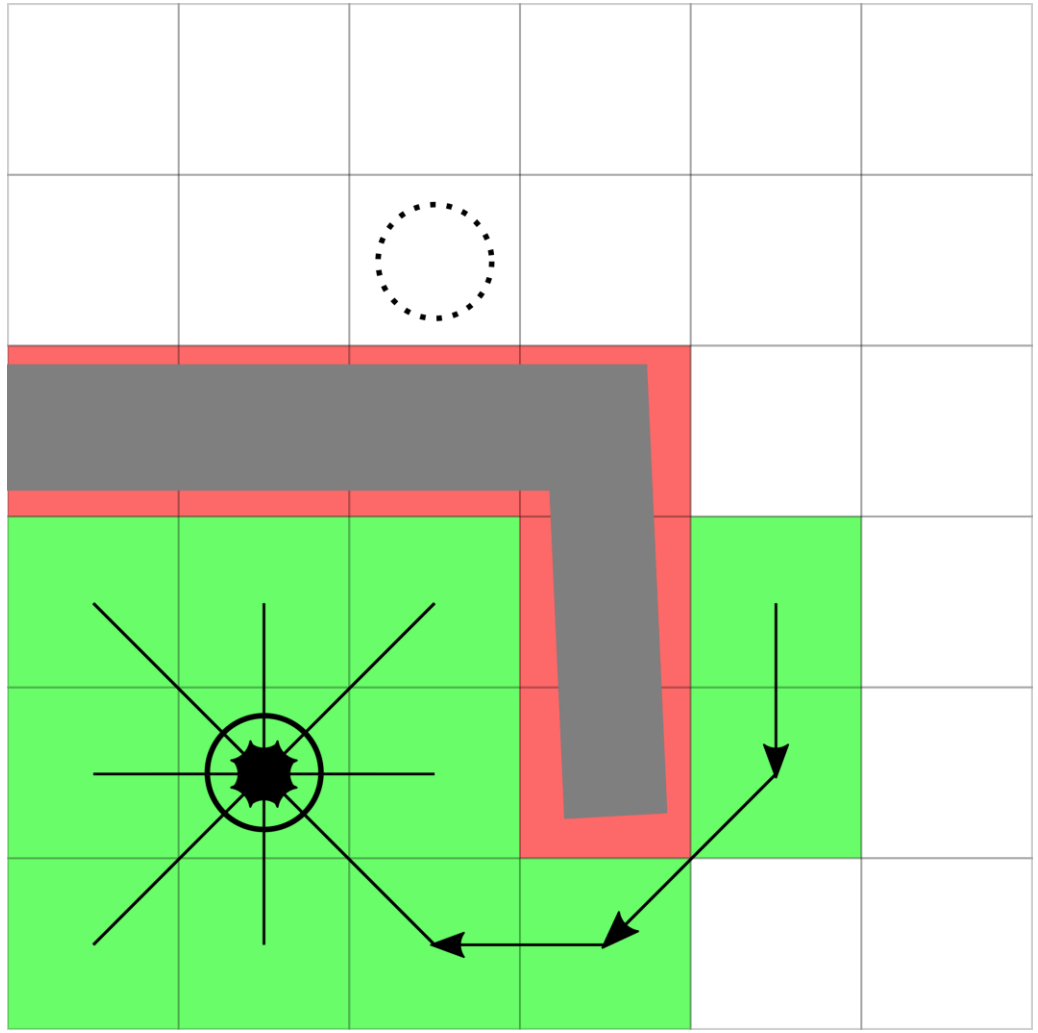
Appendix: example of A* planning

4.65	**3.41**	**3.41**	**4.23**		
4.24 g: 1.41 h: 2.83	**3.24** g: 1.00 h: 2.24	**3.41** g: 1.41 h: 2.00	**4.65**	**7.65** g: 4.82 h: 2.83	**8.84** g: 5.23 h: 3.61
4.61 g: 1.00 h: 3.61	**3.16** g: 0.00 h: 3.16	**4.00** g: 1.00 h: 3.00	**5.16**	**7.43** g: 3.82 h: 3.61	**9.06** g: 4.82 h: 4.24
5.88 g: 1.41 h: 4.47	**5.12** g: 1.00 h: 4.12	**5.41** g: 1.41 h: 4.00	**6.53** g: 2.41 h: 4.12	**7.88** g: 3.41 h: 4.47	**10.23** g: 5.23 h: 5.00



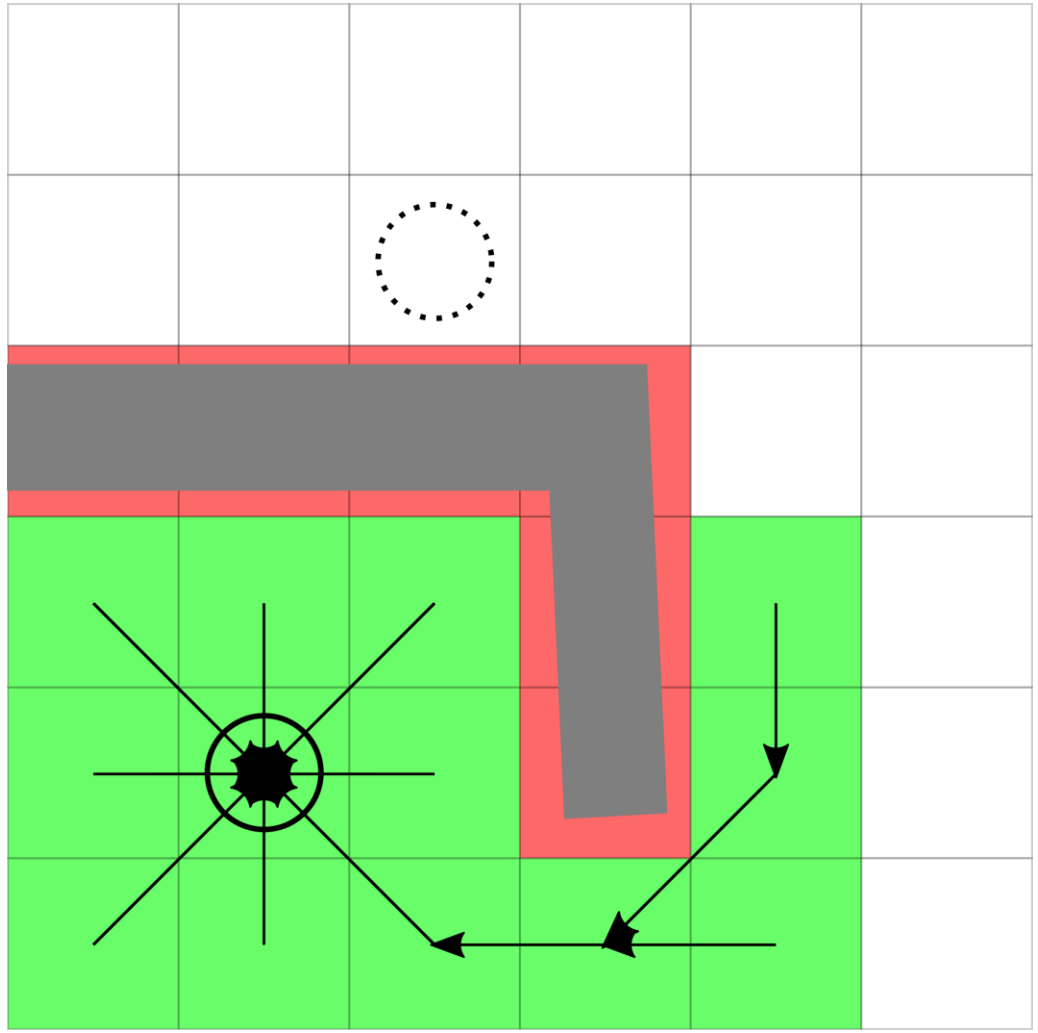
Appendix: example of A* planning

4.65	**3.41**	**3.41**	**4.23**	**8.06** g: 5.82 h: 2.24	**9.39** g: 6.23 h: 3.16
4.24 g: 1.41 h: 2.83	**3.24** g: 1.00 h: 2.24	**3.41** g: 1.41 h: 2.00	**4.65**	**7.65** g: 4.82 h: 2.83	**8.84** g: 5.23 h: 3.61
4.61 g: 1.00 h: 3.61	**3.16** g: 0.00 h: 3.16	**4.00** g: 1.00 h: 3.00	**5.16**	**7.43** g: 3.82 h: 3.61	**9.06** g: 4.82 h: 4.24
5.88 g: 1.41 h: 4.47	**5.12** g: 1.00 h: 4.12	**5.41** g: 1.41 h: 4.00	**6.53** g: 2.41 h: 4.12	**7.88** g: 3.41 h: 4.47	**10.23** g: 5.23 h: 5.00



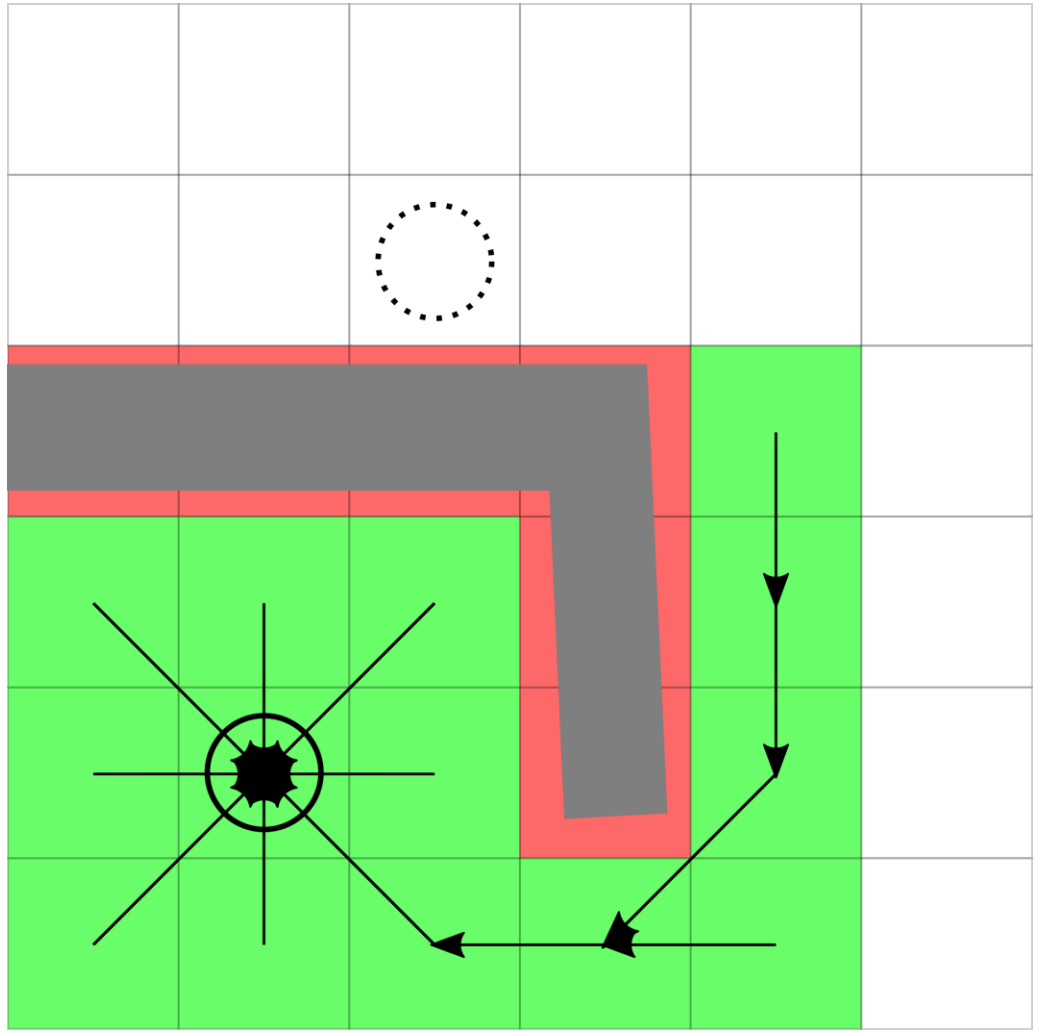
Appendix: example of A* planning

4.65	**3.41**	**3.41**	**4.23**	**8.06** g: 5.82 h: 2.24	**9.39** g: 6.23 h: 3.16
4.24 g: 1.41 h: 2.83	**3.24** g: 1.00 h: 2.24	**3.41** g: 1.41 h: 2.00	**4.65**	**7.65** g: 4.82 h: 2.83	**8.84** g: 5.23 h: 3.61
4.61 g: 1.00 h: 3.61	**3.16** g: 0.00 h: 3.16	**4.00** g: 1.00 h: 3.00	**5.16**	**7.43** g: 3.82 h: 3.61	**9.06** g: 4.82 h: 4.24
5.88 g: 1.41 h: 4.47	**5.12** g: 1.00 h: 4.12	**5.41** g: 1.41 h: 4.00	**6.53** g: 2.41 h: 4.12	**7.88** g: 3.41 h: 4.47	**9.41** g: 4.41 h: 5.00



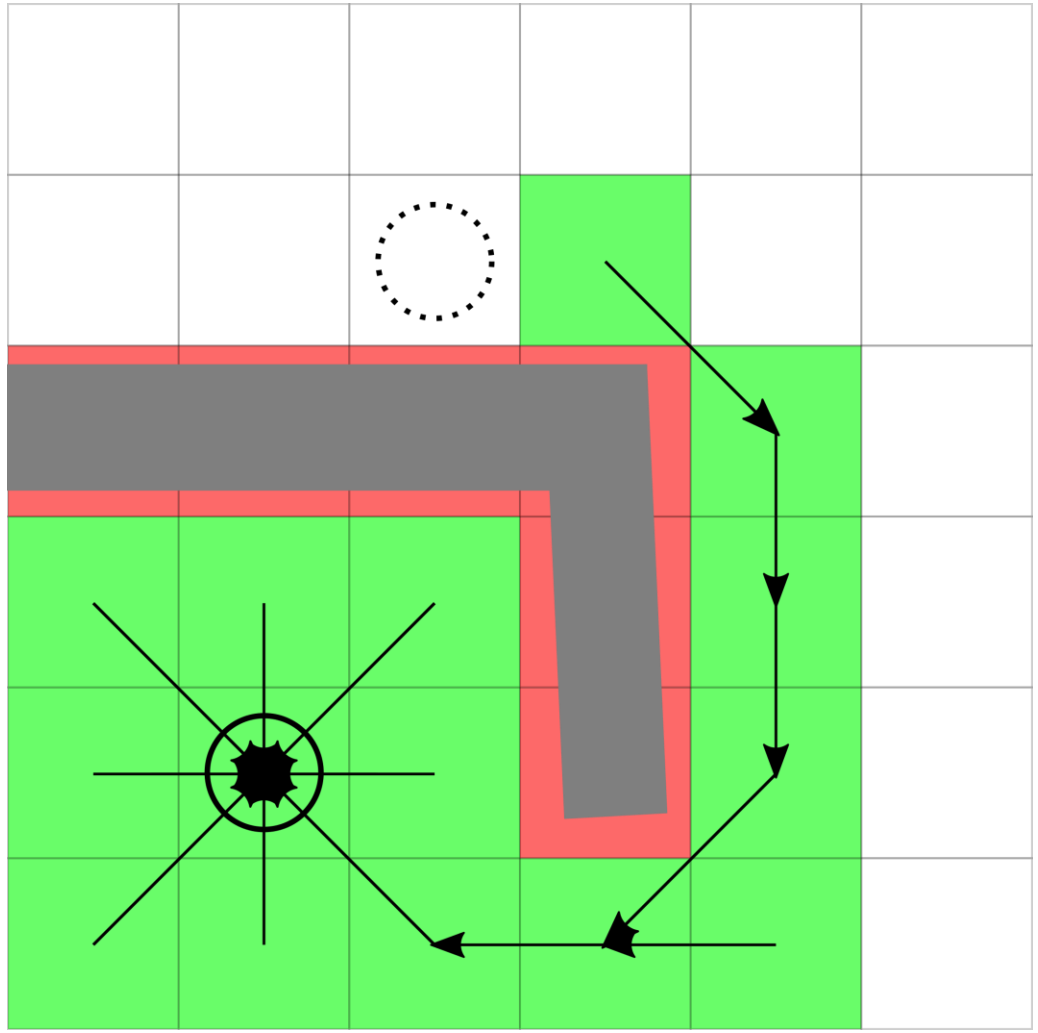
Appendix: example of A* planning

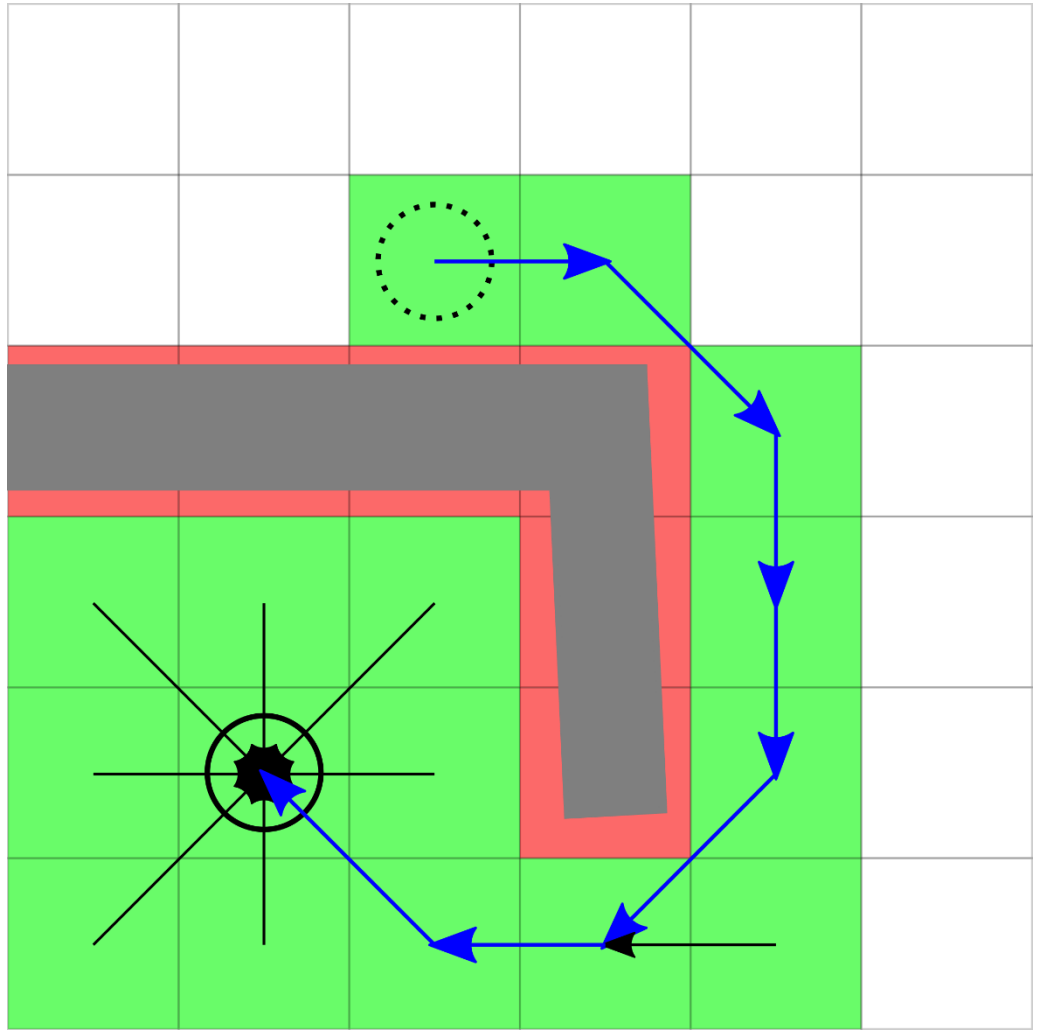
			8.23 g: 7.23 h: 1.00	**8.82** g: 6.82 h: 2.00	**10.23** g: 7.23 h: 3.00
4.65	**3.41**	**3.41**	**4.23**	**8.06** g: 5.82 h: 2.24	**9.39** g: 6.23 h: 3.16
4.24 g: 1.41 h: 2.83	**3.24** g: 1.00 h: 2.24	**3.41** g: 1.41 h: 2.00	**4.65**	**7.65** g: 4.82 h: 2.83	**8.84** g: 5.23 h: 3.61
4.61 g: 1.00 h: 3.61	**3.16** g: 0.00 h: 3.16	**4.00** g: 1.00 h: 3.00	**5.16**	**7.43** g: 3.82 h: 3.61	**9.06** g: 4.82 h: 4.24
5.88 g: 1.41 h: 4.47	**5.12** g: 1.00 h: 4.12	**5.41** g: 1.41 h: 4.00	**6.53** g: 2.41 h: 4.12	**7.88** g: 3.41 h: 4.47	**9.41** g: 4.41 h: 5.00



Appendix: example of A* planning

		9.64 g: 8.64 h: 1.00	**9.64** g: 8.23 h: 1.41	**10.88** g: 8.64 h: 2.24	
		8.23 g: 8.23 h: 0.00	**8.23** g: 7.23 h: 1.00	**8.82** g: 6.82 h: 2.00	**10.23** g: 7.23 h: 3.00
4.65	**3.41**	**3.41**	**4.23**	**8.06** g: 5.82 h: 2.24	**9.39** g: 6.23 h: 3.16
4.24 g: 1.41 h: 2.83	**3.24** g: 1.00 h: 2.24	**3.41** g: 1.41 h: 2.00	**4.65**	**7.65** g: 4.82 h: 2.83	**8.84** g: 5.23 h: 3.61
4.61 g: 1.00 h: 3.61	**3.16** g: 0.00 h: 3.16	**4.00** g: 1.00 h: 3.00	**5.16**	**7.43** g: 3.82 h: 3.61	**9.06** g: 4.82 h: 4.24
5.88 g: 1.41 h: 4.47	**5.12** g: 1.00 h: 4.12	**5.41** g: 1.41 h: 4.00	**6.53** g: 2.41 h: 4.12	**7.88** g: 3.41 h: 4.47	**9.41** g: 4.41 h: 5.00



Appendix: example of A* planning

		9.64 g: 8.64 h: 1.00	**9.64** g: 8.23 h: 1.41	**10.88** g: 8.64 h: 2.24	
		8.23 g: 8.23 h: 0.00	**8.23** g: 7.23 h: 1.00	**8.82** g: 6.82 h: 2.00	**10.23** g: 7.23 h: 3.00
4.65	**3.41**	**3.41**	**4.23**	**8.06** g: 5.82 h: 2.24	**9.39** g: 6.23 h: 3.16
4.24 g: 1.41 h: 2.83	**3.24** g: 1.00 h: 2.24	**3.41** g: 1.41 h: 2.00	**4.65**	**7.65** g: 4.82 h: 2.83	**8.84** g: 5.23 h: 3.61
4.61 g: 1.00 h: 3.61	**3.16** g: 0.00 h: 3.16	**4.00** g: 1.00 h: 3.00	**5.16**	**7.43** g: 3.82 h: 3.61	**9.06** g: 4.82 h: 4.24
5.88 g: 1.41 h: 4.47	**5.12** g: 1.00 h: 4.12	**5.41** g: 1.41 h: 4.00	**6.53** g: 2.41 h: 4.12	**7.88** g: 3.41 h: 4.47	**9.41** g: 4.41 h: 5.00