Interdisciplinary Division of Aeronautical and Aviation Engineering
航空工程跨領域學部

THE HONG KONG POLYTECHNIC UNIVERSITY
香港理工大學

AAE2004 Introduction to Aviation Systems
AAE
Design of Path Planning Algorithm for Aircraft Operation

Second Week

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Assisted by

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Lecturer's Information

- **Instructor**: Dr Li-Ta HSU
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- Office Hour: by appointment

- **Expertise:** GPS navigation, Autonomous driving, Pedestrian localization using Smartphone, Sensor Integration

Ground Rules

For students

- Try to speak as much English as possible.
- Participate the class activates assigned.

For teaching staffs

- Reply your email with 3 working day.
- Open to any question regards to the subject

For us!

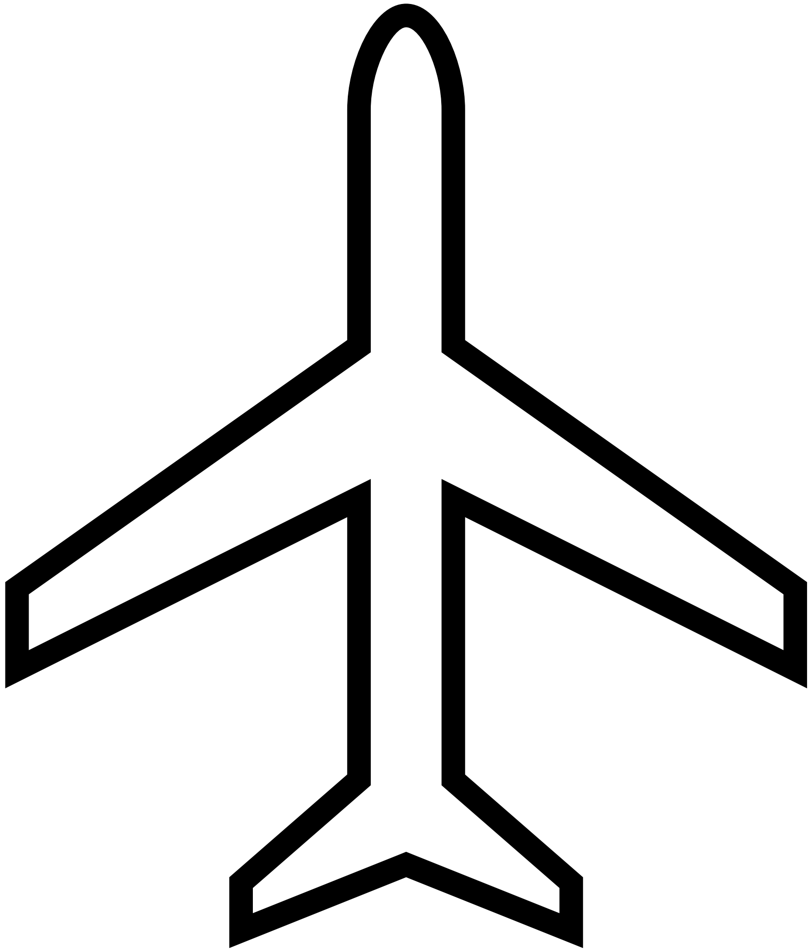
- Keep an open mind—enter the classroom dialogue with the expectation of learning something new. Look forward to learning about–and being challenged by–ideas, questions, and points of view that are different than your own.
- Arrive on time to the class and finish the class on time

Necessary Information

- Course Repository link: https://github.com/IPNL-POLYU/PolyU_AAE2004_Github_Project
- TA Information & Contact:
  - Group 1-5: Queenie Ho (hiu-yi.ho@connect.polyu.hk)
  - Group 6-10: Nikkie Leung (yan-tung.leung@connect.polyu.hk)

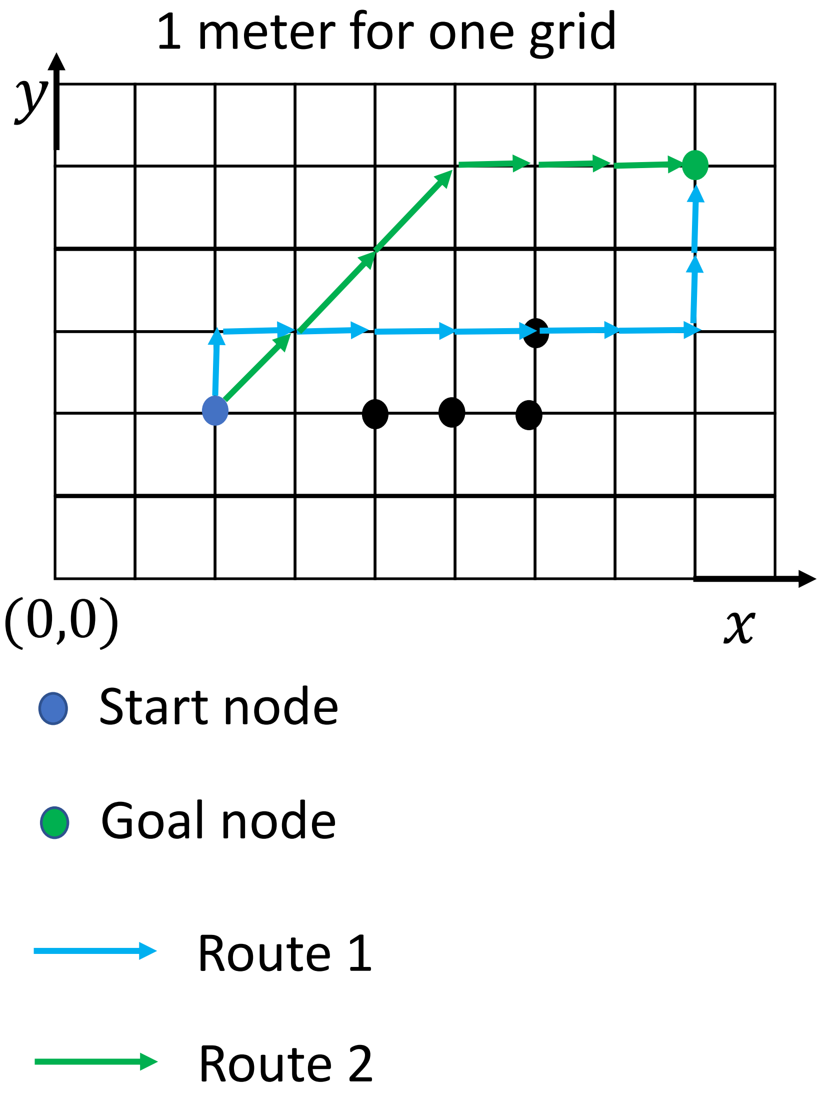
Week 2 Content

1. Introduction to A* Path Planning Algorithm
2. Cost Intensive Areas
3. Path Planning Programming Guide
4. Project Compulsory Tasks



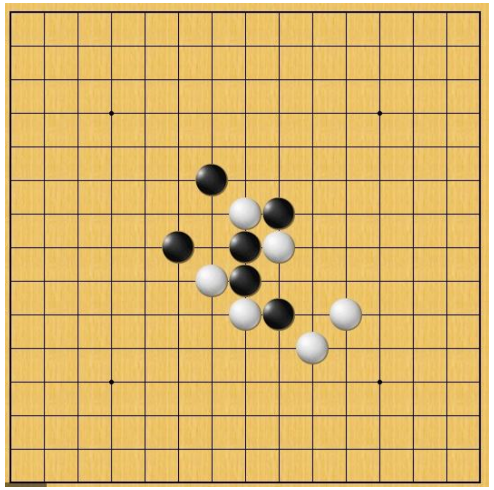
Introduction to A* Path Planning Algorithm

Definition of Path Planning



•**Node** — All potential position you can go across with a unique position (x, y)

•**Search Space** — A collection of nodes, like all board positions of a board game.

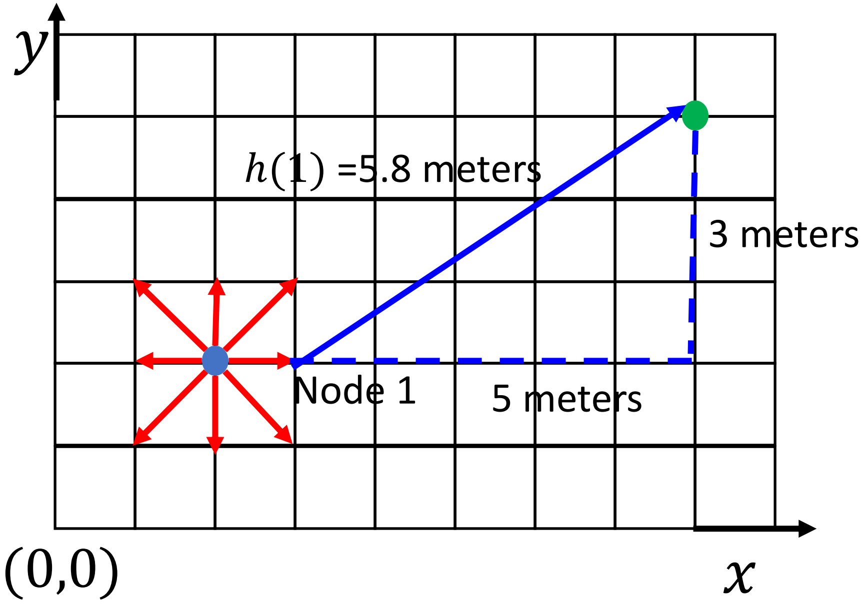


Gobang

•**Objective of path planning**— Find the shortest routes with smallest cost from start node to goal node.

How to find the shortest route!

Path Planning using A Star Method



Start node

Goal node

1 meter for one grid

Definition of cost:

$$f(x, y) \ = \ g(x, y) \ + \ h(x, y)$$

•$\boldsymbol{g}(x, y)$ — this represents the ***exact cost*** of the path from the **starting node** to node (x, y)

•$\boldsymbol{h}(x, y)$ — this represents the heuristic ***estimated cost*** from node (x, y) to the goal node.

•$\boldsymbol{f}(x, y)$ —cost of the neighboring node (x, y)

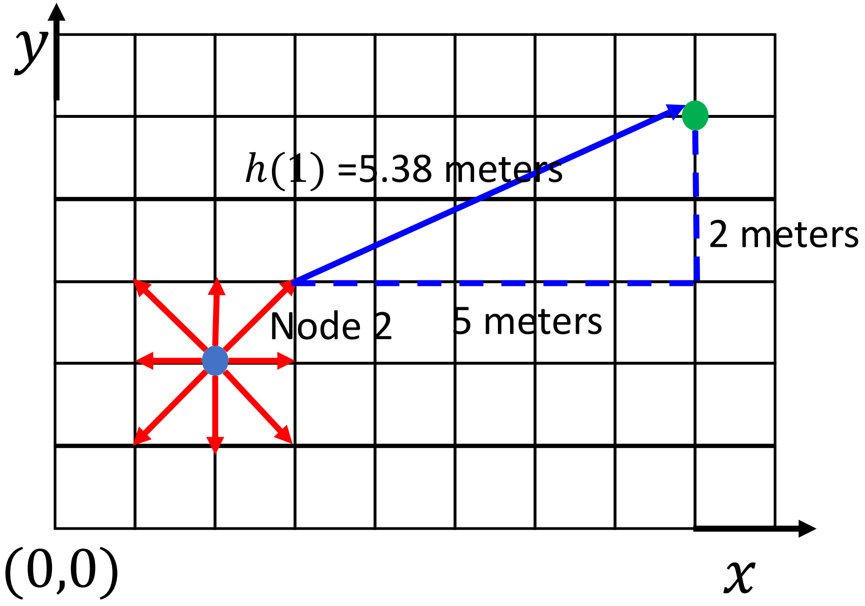
8 neighboring node and the cost can be calculated as follows!

Node 1:

$f(3,2) \ = \ g(3,2) \ + \ h(3,2)$ =6.8 meters

with $g(3,2) = 1$ meter and $h(3,2) \ = 5.8$ meters

Path Planning using A Star Method



Start node

Goal node

1 meter for one grid

Definition of cost:

$$f(x,y) = g(x,y) + h(x,y)$$

•$\boldsymbol{g}(x,y)$ — this represents the ***exact cost*** of the path from the **starting node** to node (x,y)

•$\boldsymbol{h}(x,y)$ — this represents the heuristic ***estimated cost*** from node (x,y) to the goal node.

•$\boldsymbol{f}(x,y)$ —cost of the neighboring node (x,y)

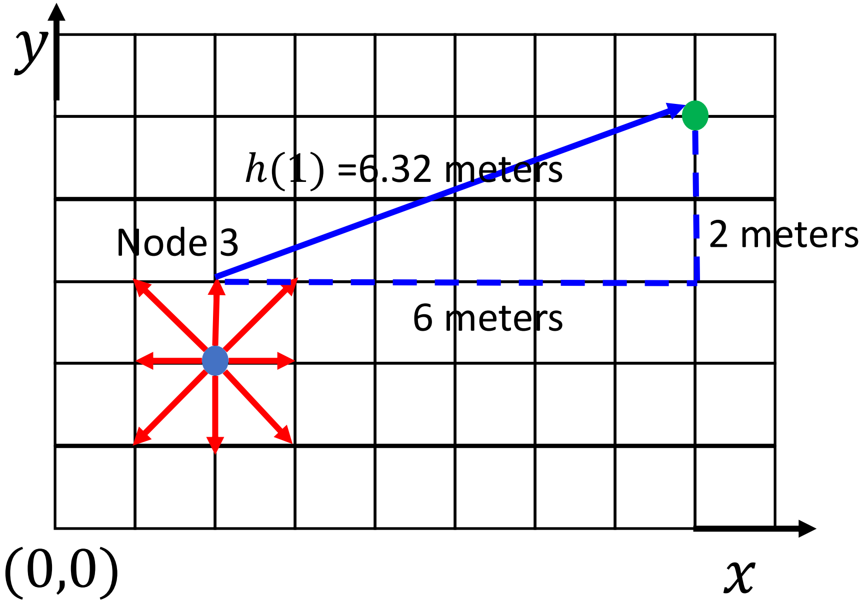
8 neighboring node and the cost can be calculated as follows!

Node 2:

$f(3,3) = g(3,3) + h(3,3)$ =6.79 meters

with $g(3,3) = \sqrt{2}$ meter and $h(3,3) = 5.38$ meters

Path Planning using A Star Method



Start node

Goal node

1 meter for one grid

Definition of cost:

$$f(x,y) = g(x,y) + h(x,y)$$

•$\boldsymbol{g}(x,y)$ — this represents the ***exact cost*** of the path from the **starting node** to node (x,y)

•$\boldsymbol{h}(x,y)$ — this represents the heuristic ***estimated cost*** from node (x,y) to the goal node.

•$\boldsymbol{f}(x,y)$ —cost of the neighboring node (x,y)

8 neighboring node and the cost can be calculated as follows!

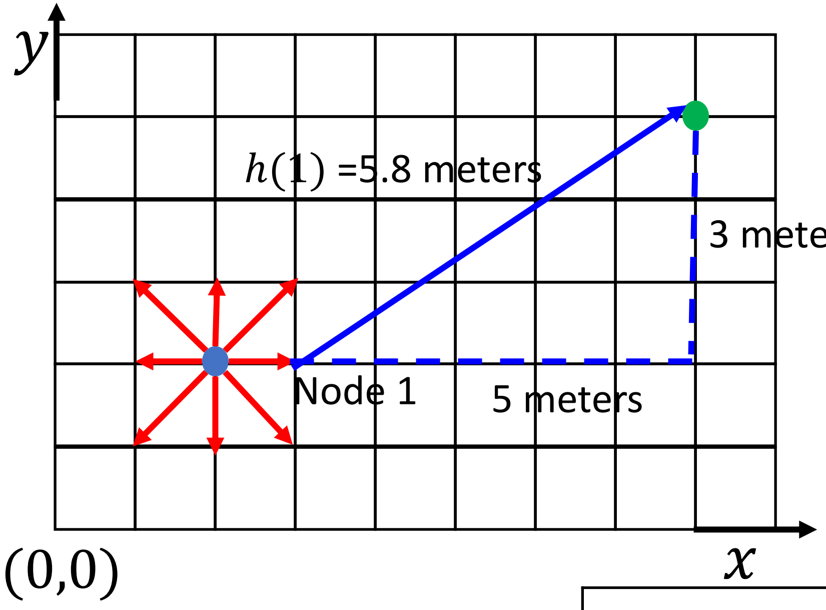
Node 3:

$f(2,3) = g(2,3) + h(2,3)$ =7.32 meters

with $g(2,3) = 1$ meter and $h(2,3) = 6.32$ meters

Similar cost calculation method for other 5 nodes

Path Planning using A Star Method



Start node

Goal node

1 meter for one grid

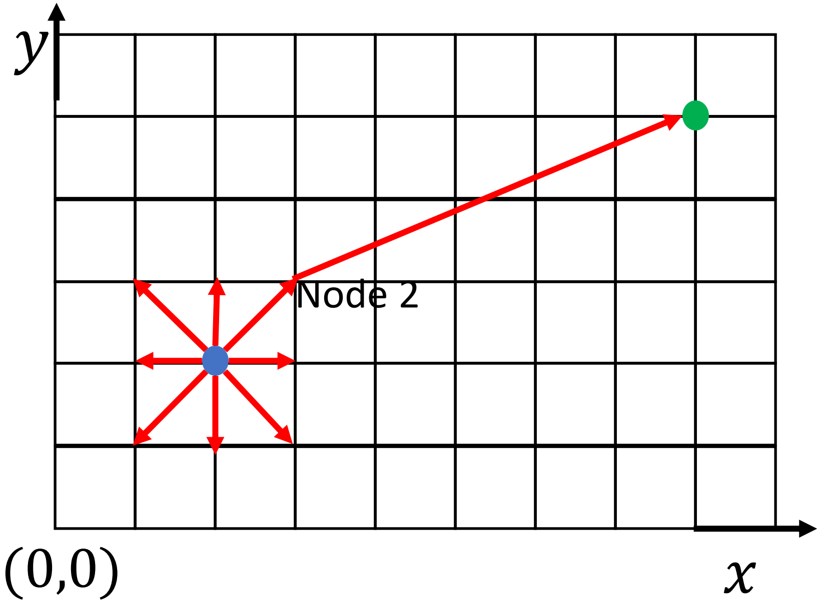
Definition of cost:

$$f(x, y) = g(x, y) + h(x, y)$$

- $\boldsymbol{g}(x, y)$ — this represents the ***exact cost*** of the path from the **starting node** to node (x, y)
- $\boldsymbol{h}(x, y)$ — this represents the heuristic ***estimated cost*** from node (x, y) to the goal node.
- $\boldsymbol{f}(x, y)$ —cost of the neighboring node (x, y)

Node (x, y)	Node 1 (x, y)	Node 2 (x, y)	Node 3 (x, y)	Node 4 (x, y)	Node 5 (x, y)	Node 6 (x, y)	Node 7 (x, y)	Node 8 (x, y)
$g(x, y)$	1	1.414	1	1.414	1	1.414	1	1.414
$h(x, y)$	5.8	5.38	6.32	7.28	7.62	8.06	7.21	6.40
$f(x, y)$	6.8	6.79	7.32	8.694	8.62	9.474	8.21	7.814

Path Planning using A Star Method



Start node

Goal node

1 meter for one grid

Definition of cost:

$$f(x,y) = g(x,y) + h(x,y)$$

•$\boldsymbol{g}(x,y)$ — this represents the ***exact cost*** of the path from the **starting node** to node (x,y)

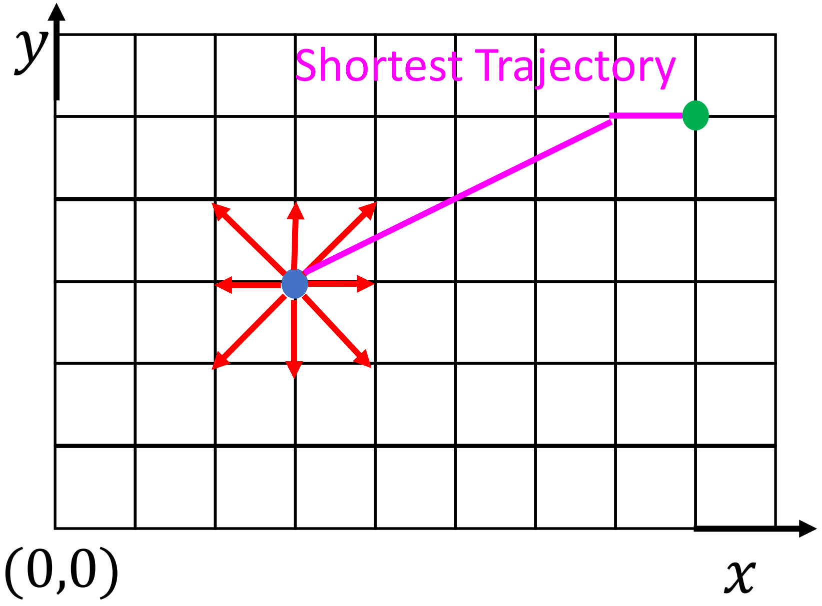
•$\boldsymbol{h}(x,y)$ — this represents the heuristic ***estimated cost*** from node (x,y) to the goal node.

•$\boldsymbol{f}(x,y)$ —cost of the neighboring node (x,y)

8 neighboring node and the cost can be calculated as follows!

Node 2 leads to smallest cost

Calculate the cost of node



Start node

Goal node

1 meter for one grid

Definition of cost:

$$f(x,y) = g(x,y) + h(x,y)$$

•$\boldsymbol{g}(x,y)$ — this represents the ***exact cost*** of the path from the **starting node** to node (x,y)

•$\boldsymbol{h}(x,y)$ — this represents the heuristic ***estimated cost*** from node (x,y) to the goal node.

•$\boldsymbol{f}(x,y)$ —cost of the neighboring node (x,y)

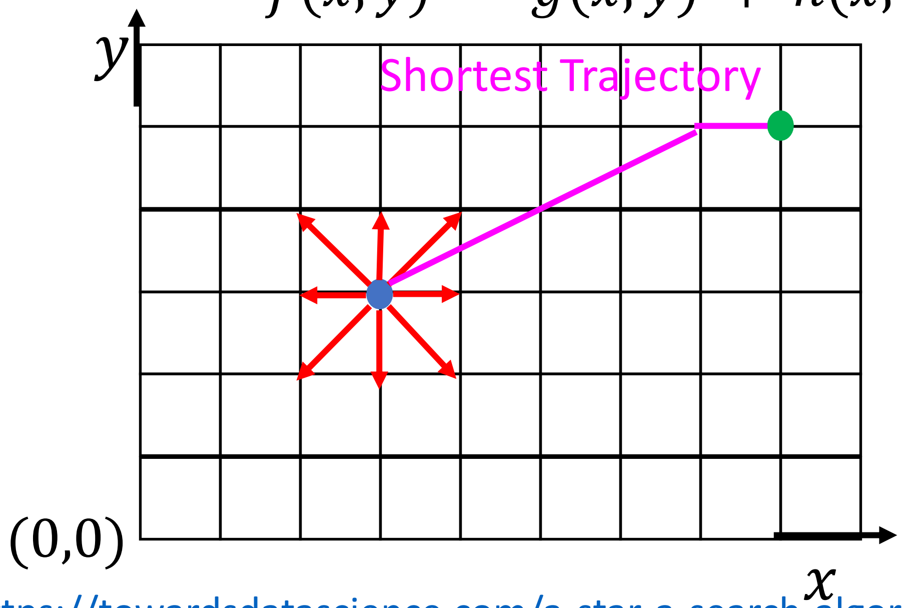
8 neighboring node and the cost can be calculated as follows!

Search from the neighbouring node with smallest cost until reaching the goal!

A star method example

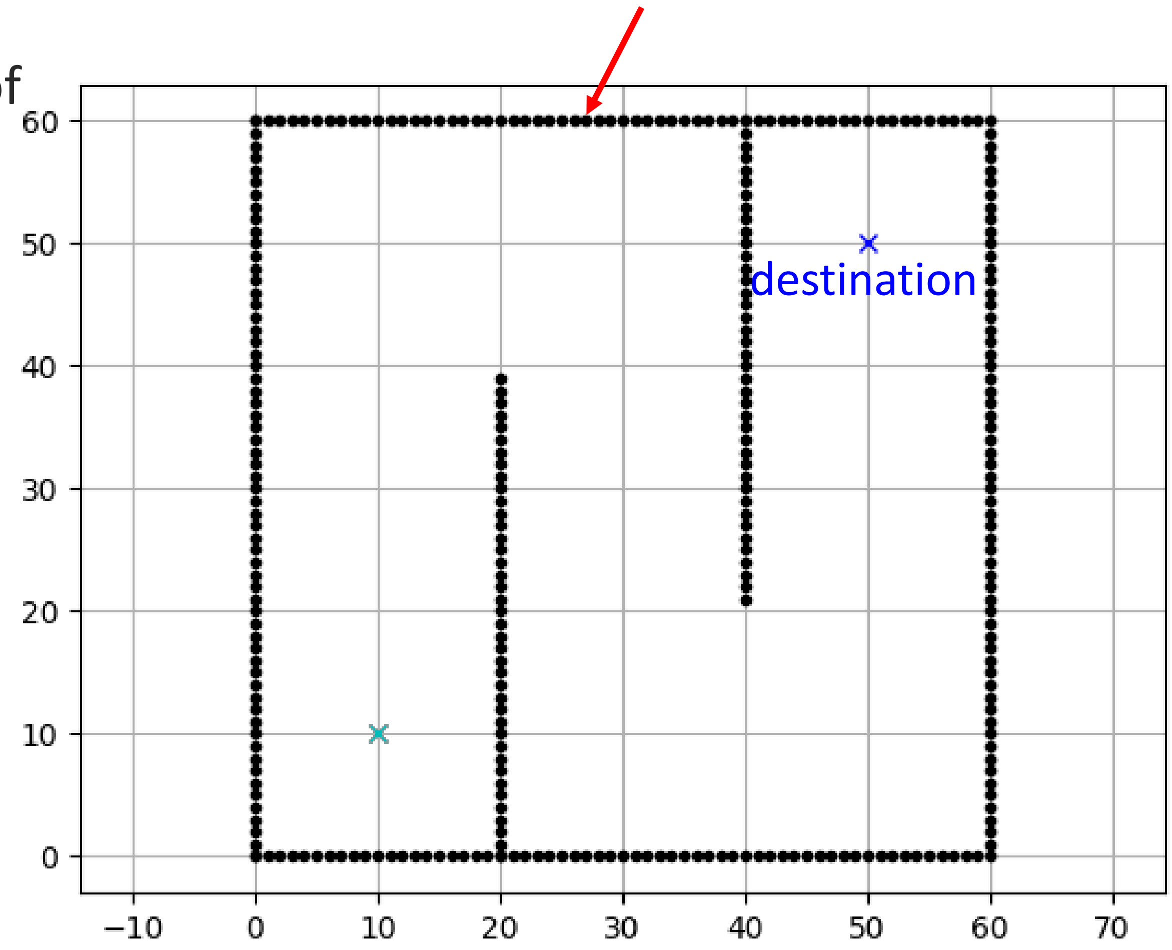
Each time A* enters a node, it calculates the cost, f(n)(n being the neighboring node), to travel to all of the neighboring nodes, and then enters the node with the lowest value of f(n).
These values we calculate using the following formula:

$$f(x,y) = g(x,y) + h(x,y)$$



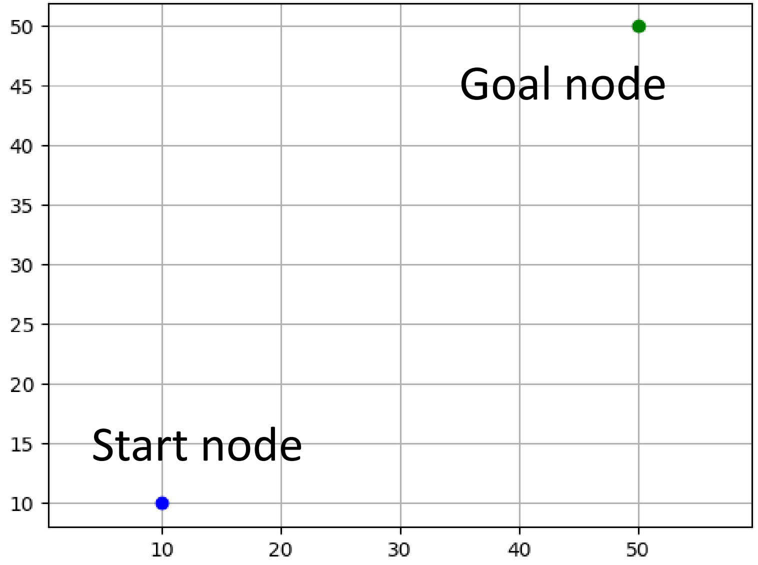
https://towardsdatascience.com/a-star-a-search-algorithm-eb495fb156bb

Wall (obstacles) cannot be touched!



Source: PythonRobotics

Code: set up start and goal node



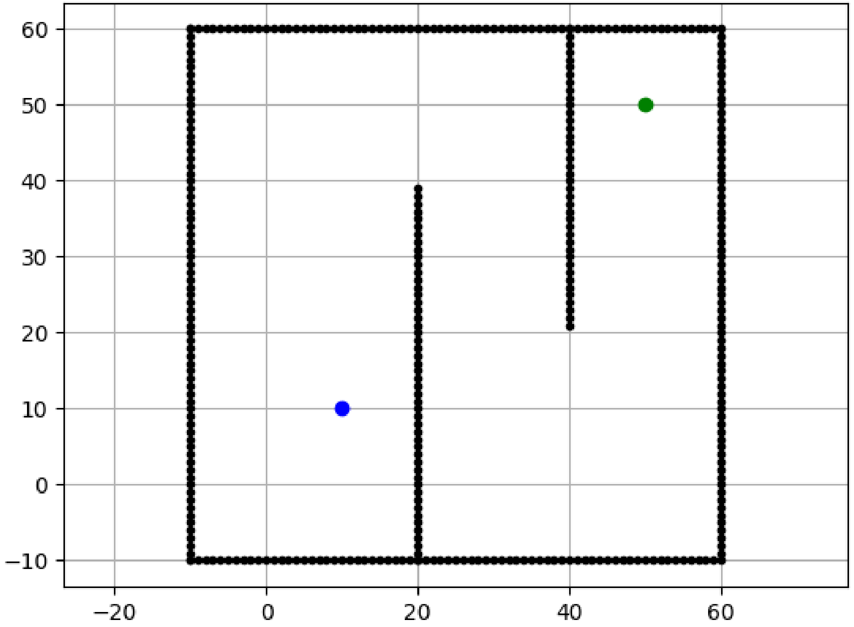
Set up the start and goal nodes using the code

```
# start and goal position
sx = 10.0  # [m]
sy = 10.0  # [m]
gx = 50.0  # [m]
gy = 50.0  # [m]
grid_size = 2  # [m]
```

- Start node
- Goal node

Base code tutorial: https://www.youtube.com/watch?v=PRKLhcG2kB0&ab_channel=POLYUIPNL

Code: set up obstacle

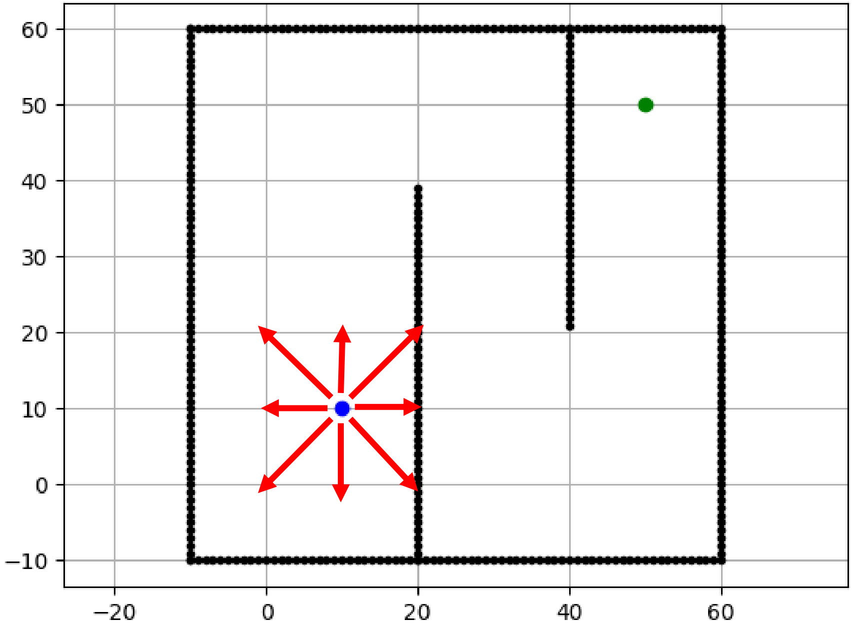


- Start node
- Goal node
- Obstacle (wall)

Set up the obstacle using the code

```
# set obstacle positions
ox, oy = [], []
for i in range(-10, 60): # draw the button border
    ox.append(i)
    oy.append(-10.0)
for i in range(-10, 60):
    ox.append(60.0)
    oy.append(i)
for i in range(-10, 61):
    ox.append(i)
    oy.append(60.0)
for i in range(-10, 61):
    ox.append(-10.0)
    oy.append(i)
for i in range(-10, 40):
    ox.append(20.0)
    oy.append(i)
for i in range(0, 40):
    ox.append(40.0)
    oy.append(60.0 - i)
```

Code: neighboring node search



- Start node
- Goal node
- Obstacle (wall)

neighboring node search

```python
def get_neighbouring_node(): # the cost of the surrounding 8 points
    # dx, dy, cost
    motion = [[1, 0, 1],
              [0, 1, 1],
              [-1, 0, 1],
              [0, -1, 1],
              [-1, -1, math.sqrt(2)],
              [-1, 1, math.sqrt(2)],
              [1, -1, math.sqrt(2)],
              [1, 1, math.sqrt(2)]]

    return motion
```

Code: cost calculation

Heuristic cost$g(x,y)$ calculation

```python
def calc_heuristic(n1, n2):
    w = 1.0  # weight of heuristic
    d = w * math.hypot(n1.x - n2.x, n1.y - n2.y)
    return d
```

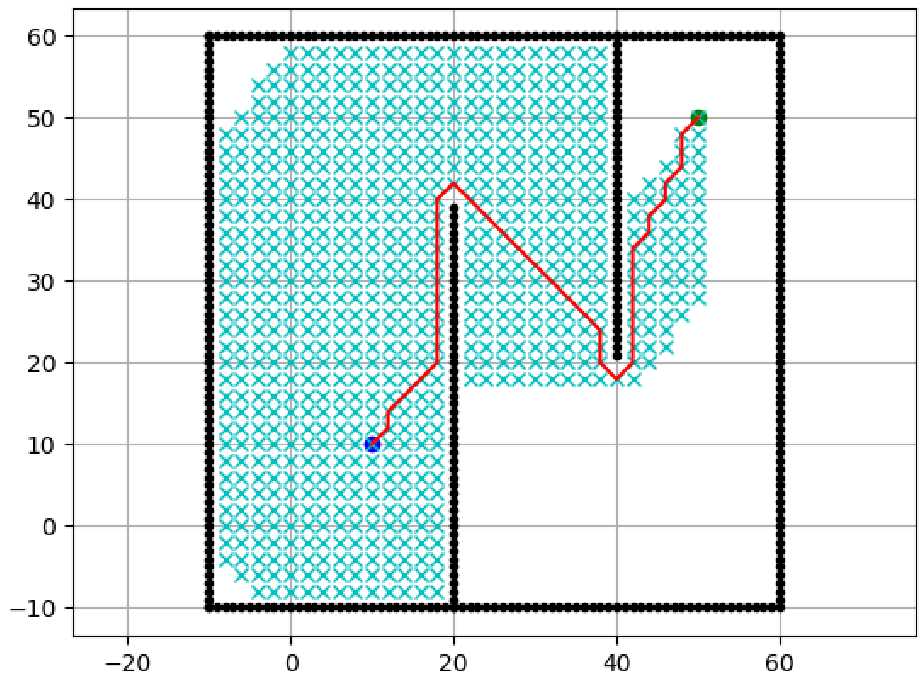
exact cost $g(x,y)$ calculation

```python
node = self.Node(current.x + self.motion[i][0],
                 current.y + self.motion[i][1],
                 current.cost + self.motion[i][2], c_id)
```

Code: calculation of final path

```
def calc_final_path(self, goal_node, closed_set):
    # generate final course
    rx, ry = [self.calc_grid_position(goal_node.x, self.min_x)], [
        self.calc_grid_position(goal_node.y, self.min_y)] # save the goal node as the first point
    parent_index = goal_node.parent_index
    while parent_index != -1:
        n = closed_set[parent_index]
        rx.append(self.calc_grid_position(n.x, self.min_x))
        ry.append(self.calc_grid_position(n.y, self.min_y))
        parent_index = n.parent_index

    return rx, ry
```



Cost Intensive Areas

Flight planning considering trip cost

The fundamental rationale of the cost index concept is to achieve minimum trip cost by means of a trade-off between operating costs per hour and incremental fuel burn.

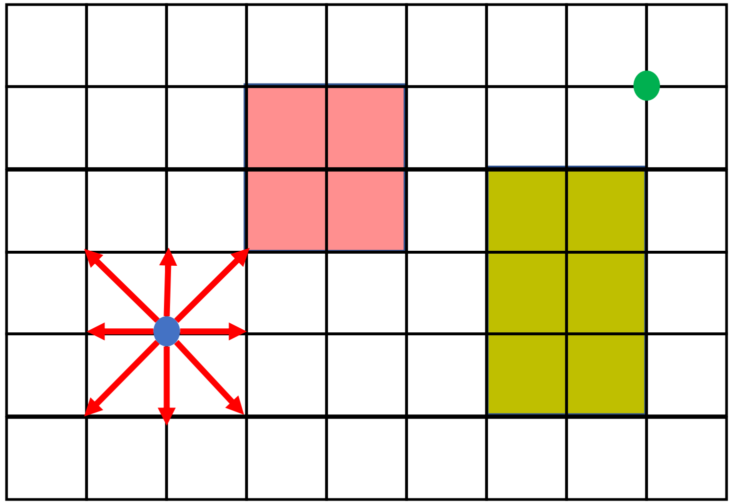
$$\mathrm{C} = C_F \cdot \Delta F + C_T \cdot \Delta T + C_c$$

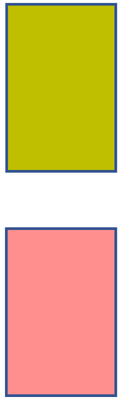
With

- C_F=cost of fuel per kg
- C_T=time related cost per minute of flight
- C_c=fixed cost independent of time
- C_T=time related cost per minute of flight
- ΔF=trip fuel (e.g. 3000kg/h)
- ΔT=trip Time (e.g. 8 hours from Hong Kong to Paris)

Can we consider this cost to our path planning to imitate the path planning for flights?

Flight planning considering trip cost





Cost Intensive Areas: the cost for flying through such area is increased due to airflow, legal restrictions and other reasons. (additional cost ΔF_a, ΔT_a)

- Start node
- Goal node

Cost can be calculated using the following formula:

$$f(x,y) = g(x,y) + h(x,y)$$

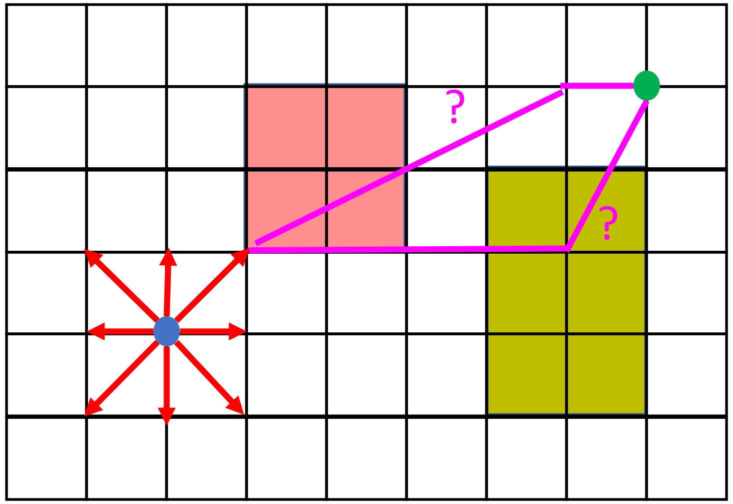
One white grid with cost as follows for $g(x,y)\&h(x,y)$:

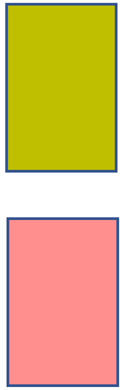
$$\mathrm{C} = C_F \cdot \Delta F + C_T \cdot \Delta T + C_c$$

One colored grid with cost as follows for $g(x,y)\&h(x,y)$:

$$\mathrm{C} = C_F \cdot (\Delta F + \Delta F_a(x,y)) + C_T \cdot (\Delta T + \Delta T_a(x,y)) + C_c$$

How we choose the routes ?





Cost Intensive Areas: the cost for flying through such area is increased due to airflow, legal restrictions and other reasons. (additional cost ΔF_a, ΔT_a)

- Start node
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Cost can be calculated using the following formula:

$$f(x,y) = g(x,y) + h(x,y)$$

One white grid with cost as follows for $g(x,y)\&h(x,y)$:

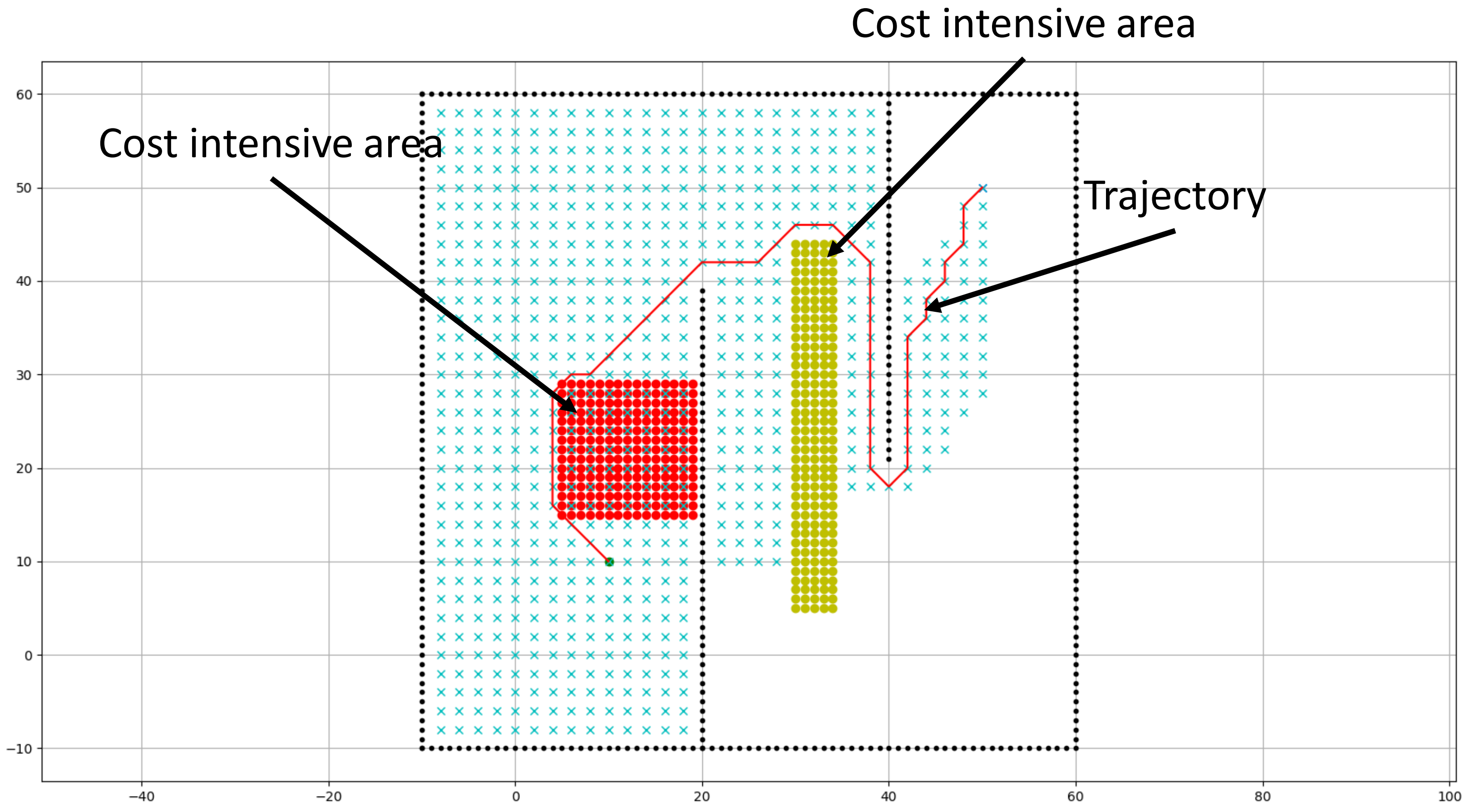
$$\mathrm{C} = C_F \cdot \Delta F + C_T \cdot \Delta T + C_c$$

One colored grid with cost as follows for $g(x,y)\&h(x,y)$:

$$\mathrm{C} = C_F \cdot (\Delta F + \Delta F_a(x,y)) + C_T \cdot (\Delta T + \Delta T_a(x,y)) + C_c$$

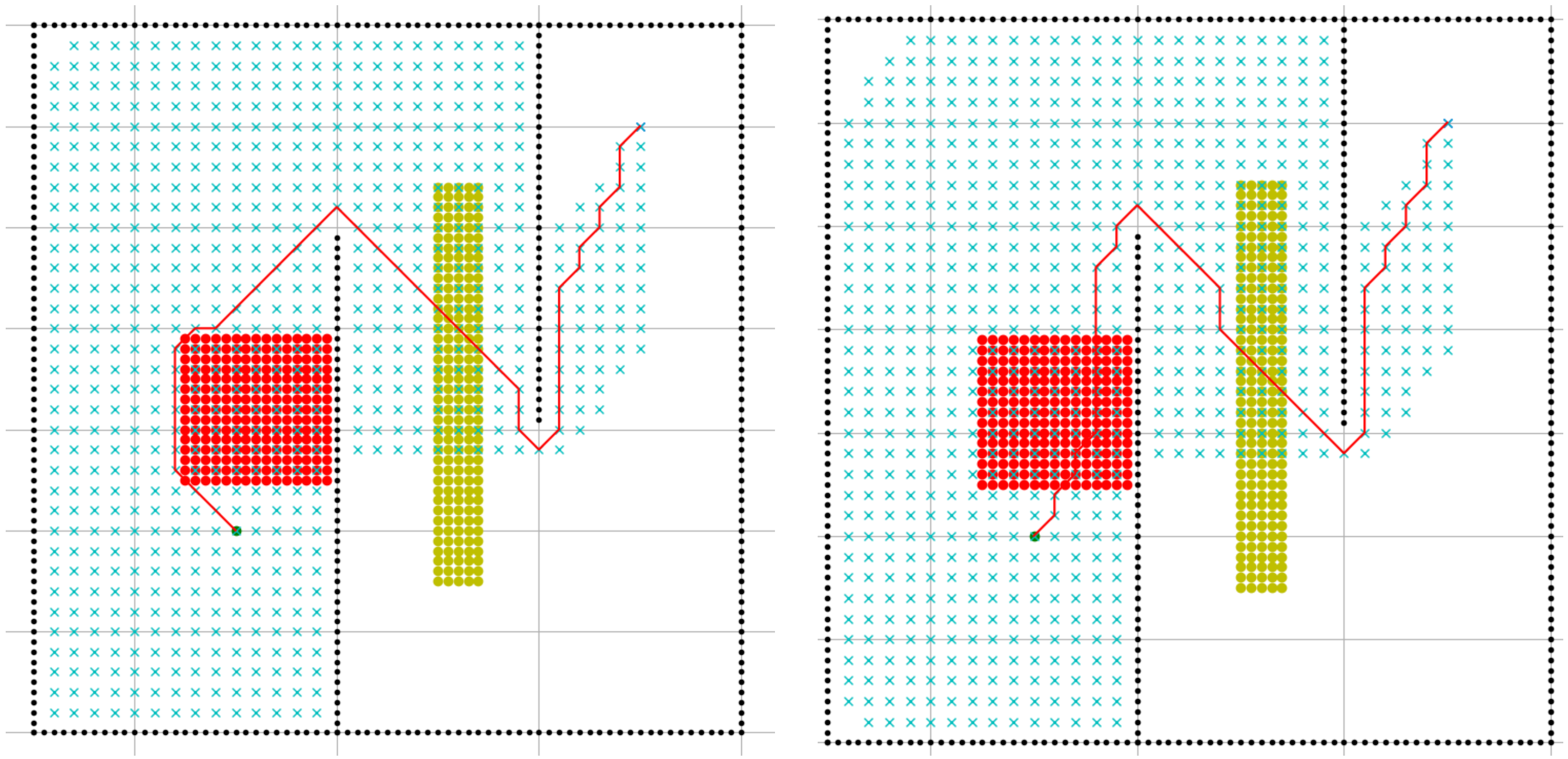
It depends on the ΔF_a and ΔT_a

Example route planning



Avoiding the Cost intensive areas if their cost is too high?

Example route planning



Go through the Cost intensive area if their additional cost is quite small?

Path Planning Project

- You will be creating and completing your own path planning program based on groups
- You can find the project tasks / requirements in this slide after the code tutorial
- Additional resources could be found inside the course GitHub repository
    - Video tutorial
    - Tutorial slides

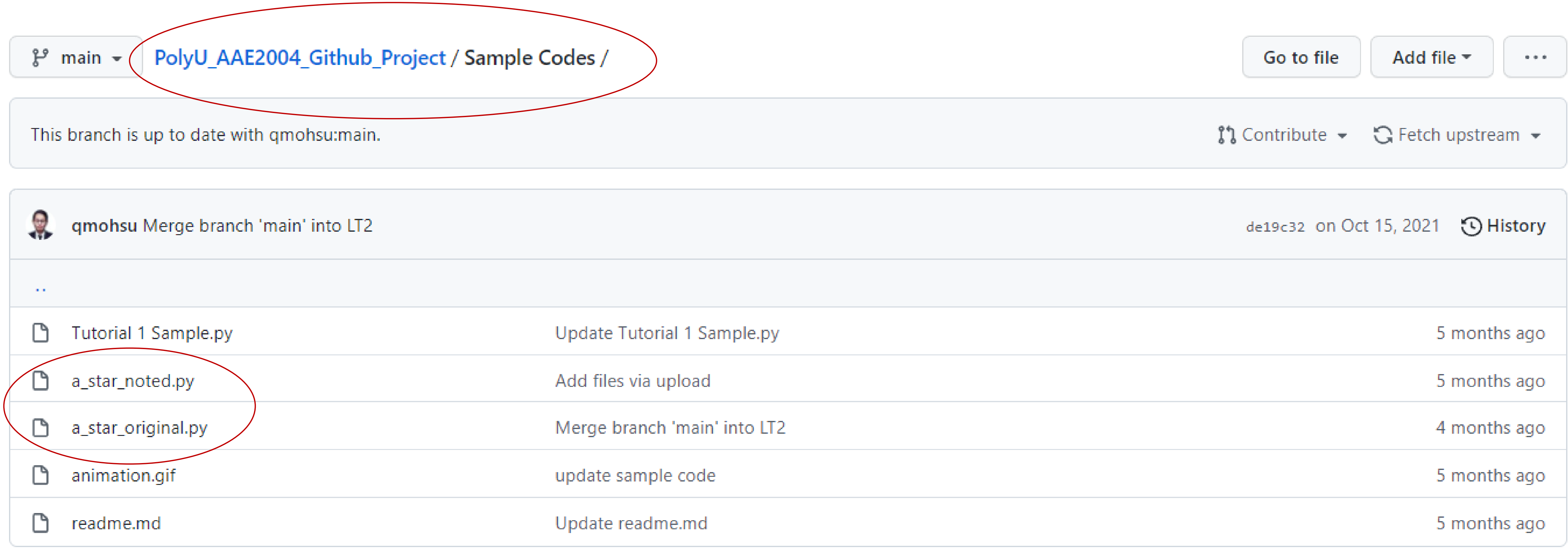
Path Planning Programming Guide

The Path Planning Code

Base code tutorial: https://www.youtube.com/watch?v=PRKLhcG2kB0&ab_channel=POLYUIPNL

- You can find the path planning code inside the course GitHub repository
- There are 2 set of codes:
  - A default one
  - A noted one
- The default one is a basic A* path planning code without any extra information and features
- The noted one provides an example of what your code should look like after modifications (Remember each group should complete a different set of obstacles and requirements)
- Repository link: https://github.com/IPNL-POLYU/PolyU_AAE2004_Github_Project

Where you can find the code



Noted Version Guide

- Line 50,51: Declaration of cost intensive area cost modifier
- Line 53: Declare cost per grid

```
34
35         self.resolution = resolution # get resolution of the grid
36         self.rr = rr # robot radis
37         self.min_x, self.min_y = 0, 0
38         self.max_x, self.max_y = 0, 0
39         self.obstacle_map = None
40         self.x_width, self.y_width = 0, 0
41         self.motion = self.get_motion_model() # motion model for grid search expansion
42         self.calc_obstacle_map(ox, oy)
43
44         self.fc_x = fc_x
45         self.fc_y = fc_y
46         self.tc_x = tc_x
47         self.tc_y = tc_y
48
49
50         self.Delta_C1 = 0.2 # cost intensive area 1 modifier
51         self.Delta_C2 = 0.4 # cost intensive area 2 modifier
52
53         self.costPerGrid = 1
54
```

Noted Version Guide

- Line 115: Showing the final calculation of total trip time
- Line 135-144: Adding additional cost during cost intensive area

```
103 if show_animation:  # pragma: no cover
104     plt.plot(self.calc_grid_position(current.x, self.min_x),
105              self.calc_grid_position(current.y, self.min_y), "xc")
106     # for stopping simulation with the esc key.
107     plt.gcf().canvas.mpl_connect('key_release_event',
108                                  lambda event: [exit(
109                                      0) if event.key == 'escape' else None])
110     if len(closed_set.keys()) % 10 == 0:
111         plt.pause(0.001)
112 
113 # reaching goal
114 if current.x == goal_node.x and current.y == goal_node.y:
115     print("Total Trip time required -> ",current.cost )
116     goal_node.parent_index = current.parent_index
117     goal_node.cost = current.cost
118     break
119 
120 # Remove the item from the open set
121 del open_set[c_id]
122 
123 # Add it to the closed set
124 closed_set[c_id] = current
125 
126 # print(len(closed_set))
127 
128 # expand_grid search grid based on motion model
129 for i, _ in enumerate(self.motion): # tranverse the motion matrix
130     node = self.Node(current.x + self.motion[i][0],
131                      current.y + self.motion[i][1],
132                      current.cost + self.motion[i][2] * self.costPerGrid, c_id)
133 
134     ## add more cost in cost intensive area 1
135     if self.calc_grid_position(node.x, self.min_x) in self.tc_x:
136         if self.calc_grid_position(node.y, self.min_y) in self.tc_y:
137             # print("cost intensive area!!")
138             node.cost = node.cost + self.Delta_C1 * self.motion[i][2]
139 
140     # add more cost in cost intensive area 2
141     if self.calc_grid_position(node.x, self.min_x) in self.fc_x:
142         if self.calc_grid_position(node.y, self.min_y) in self.fc_y:
143             # print("cost intensive area!!")
144             node.cost = node.cost + self.Delta_C2 * self.motion[i][2]
145         # print()
```

Noted Version Guide

- Line 263-270: Declaring motions for the aircraft
- Line 279-284: Declaring starting point and end point

```python
260     @staticmethod
261     def get_motion_model(): # the cost of the surrounding 8 points
262         # dx, dy, cost
263         motion = [[1, 0, 1],
264                   [0, 1, 1],
265                   [-1, 0, 1],
266                   [0, -1, 1],
267                   [-1, -1, math.sqrt(2)],
268                   [-1, 1, math.sqrt(2)],
269                   [1, -1, math.sqrt(2)],
270                   [1, 1, math.sqrt(2)]]
271 
272         return motion
273 
274 
275 def main():
276     print(__file__ + " start the A star algorithm demo !!") # print simple notes
277 
278     # start and goal position
279     sx = 0.0  # [m]
280     sy = 0.0  # [m]
281     gx = 50.0  # [m]
282     gy = 0.0  # [m]
283     grid_size = 1  # [m]
284     robot_radius = 1.0  # [m]
```

Noted Version Guide

- Line 309-329: Adding obstacles
- Line 337-348, Adding cost intensive areas (Hint: Refer to this part for your task 2!)

```
308     # set obstacle positions for group 9
309     ox, oy = [], []
310     for i in range(-10, 60): # draw the button border
311         ox.append(i)
312         oy.append(-10.0)
313     for i in range(-10, 60): # draw the right border
314         ox.append(60.0)
315         oy.append(i)
316     for i in range(-10, 60): # draw the top border
317         ox.append(i)
318         oy.append(60.0)
319     for i in range(-10, 60): # draw the left border
320         ox.append(-10.0)
321         oy.append(i)
322
323     for i in range(-10, 30): # draw the free border
324         ox.append(20.0)
325         oy.append(i)
326
327     for i in range(0, 20):
328         ox.append(i)
329         oy.append(-1 * i + 10)
330
331     # for i in range(40, 45): # draw the button border
332     #     ox.append(i)
333     #     oy.append(30.0)
334
335
336     # set cost intesive area 1
337     fc_x, fc_y = [], []
338     for i in range(30, 40):
339         for j in range(0, 40):
340             fc_x.append(i)
341             fc_y.append(j)
342
343     # set cost intesive area 1
344     tc_x, tc_y = [], []
345     for i in range(10, 20):
346         for j in range(20, 50):
347             tc_x.append(i)
348             tc_y.append(j)
```

Noted Version Guide

- If you wish to do the calculation using the program, you should add the calculation function under line 117, inside the reaching goal condition
- It would be even better if the program could distinguish viable and non-viable aircraft types!
- Use the noted version as your sample to modify your own code!

Program Calculation for Task 1

- When you add in a cost calculation function, the output should look something like this, it should be able to:

1. Calculate each aircraft types’ operating costs
2. Mention which type might not be viable for certain scenarios

```
min_x: -10
min_y: -10
max_x: 60
max_y: 60
x_width: 70
y_width: 70
Total travelling time ->  93.35575746753788
A321 not viable!
Total cost of operating A330 in this scenario:  27360.167918740684
Total cost of operating A350 in this scenario:  30752.648960130347
```

Project Compulsory Tasks

Tasks of this Freshman Project – Path Planning

1. Find the suitable aircraft models that achieve the minimum cost for the challenge assigned to your group. (Satisfactory)
2. Design a new cost area that can reduce the cost of the route. (Excellence)
3. Design a new aircraft model within the constrains to achieve minimum cost for your group challenge.
4. Additional Tasks (see different slide)

The assessment of path planning part is based on the completion and the performance of 1, 2, 3 (compulsory) and 4 (additional), based on your codes, answers on your report and presentation

The Aircraft Models

- There are many types of aircrafts nowadays!
- Airbus, Boeing, Bombardier and more!
- Each aircraft has different properties
  - Capacity (Passenger and cargo)
  - **COST!**
- Costs of operating an aircraft might include:
  - **Crew cost**
  - **Fuel cost**
  - **Other operational costs**
  - **To keep it simple, costs can be calculated by:**

$$C = C_F \cdot \Delta F + C_T \cdot \Delta T + C_c$$

With

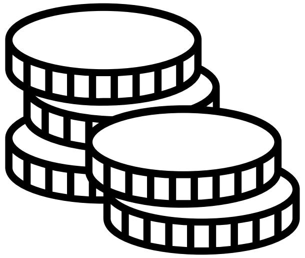
- C_F=cost of fuel per kg
- C_T=time related cost per minute of flight
- C_c=fixed cost independent of time
- C_T=time related cost per minute of flight
- ΔF=trip fuel
- ΔT=trip time
- C = total trip cost

Find the Aircraft Model that achieve minimum cost for each scenario for the challenge assigned to your group.

Task 1

Task 1

- You will be given 3 scenarios, each with different requirements to complete a functioning flight route
- Your task is to find out a shortest route from the departure point to the arrival point, then find out which type of aircraft to use for each scenario to achieve MINIMUM COST while fulfilling the passenger needs
- 3 main factors affecting the total cost:
    1. Shortest distance between your departure and arrival point
    2. Cost intensive area that the flight path might pass through
    3. Aircraft Fuel and Time costs



- Check out the example to understand this task better!

Task 1

- Restrictions and rules:
  - Only consider cruise time
  - Increase flight time by 20% and 40% respectively for cost intensive area 1 and 2 (What originally takes 1 minute to travel will take more time to travel!)
  - Only consider one type of aircraft per scenario
  - Time cost stays the same regardless of any vacancy in an aircraft
  - Only consider the 3 provided aircraft types
  - Each group must use their own obstacle set
  - Assume all aircrafts take 1 minute to travel one unit in the path planning algorithm (More cost for diagonal movements!)
  - **You must calculate the distance of the fastest path by using and modifying the program**
  - You may do the calculations using manually, but doing the calculation using programming will grant you bonus marks!

- Numbers

	A321neo	A330-900neo	A350-900
Fuel Consumption rate (kg/min)	54	84	90
Passenger Capacity	200	300	350
Time cost (Low) ($/min)	10	15	20
Time cost (Medium) ($/min)	15	21	27
Time cost (High) ($/min)	20	27	34
Fixed Cost (C_c) ($)	1800	2000	2500
Source: https://www.airlines-inform.com/			

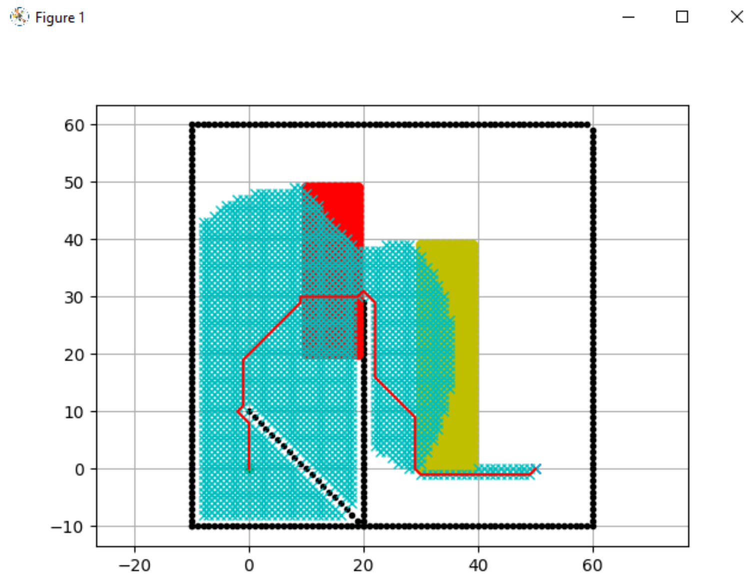
$$C = C_F \cdot \Delta F + C_T \cdot \Delta T + C_c$$

With

- C_F=cost of fuel per kg
- C_T=time related cost per minute of flight
- C_c=fixed cost independent of time
- C_T=time related cost per minute of flight
- ΔF=trip fuel
- ΔT=trip time
- C = total trip cost

Task 1 Example (Step-by-step)

- Example Scenario:
    1. 2000 Passengers need to travel this week from the start to the destination
    2. 10 flights maximum for one week
    3. Time cost = low and Fuel cost = 0.8 $/kg
- First step: Find the shortest path for your obstacle set
    1. Set up your obstacles and cost intensive areas using the path planning programme
    2. Modify the program so it will calculate the unit travelled, hence cost via the shortest path (Remember the modifier for cost intensive areas!)
    3. In this example, the shortest path is assumed to be 100 units. After accounting for the cost intensive areas, the time required is 120 minutes



What the working program should look like

Task 1 tutorial video:
https://youtu.be/hmlWX5OEs5U

Task 1 Example (Step-by-step)

- Second step: Consider the Cost Factors
  1. Since we can only operate 10 flights max, the viable options are ten A321 flights, seven A330 flights or six A350 flights to fulfil the 2000 passenger demand
  2. We can now calculate the total cost using numbers we have and the cost equation:
     A321: (0.8$/kg x 120min x 54 kg/min + 10 $/min x 120 min + 1800) x 10 flights = $81840
     A330: (0.8$/kg x 120min x 84 kg/min + 15 $/min x 120 min + 2000) x 7 flights = $83048
     A350: (0.8$/kg x 120min x 90 kg/min + 20 $/min x 120 min + 2600) x 6 flights = $81240
  3. **As the total cost of operating A350 is the lowest, the answer for this example is 6 flights of A350!**

What is required in your code:

1. Coding with:
   1. Path planning set for your group
   2. (Cost calculation, not mandatory)

	A321neo	A330-900neo	A350-900
Fuel Consumption rate (kg/min)	54	84	90
Passenger Capacity	200	300	350
Time cost (Low) ($/min)	10	15	20
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$$C = C_F \cdot \Delta F + C_T \cdot \Delta T + C_c$$

With

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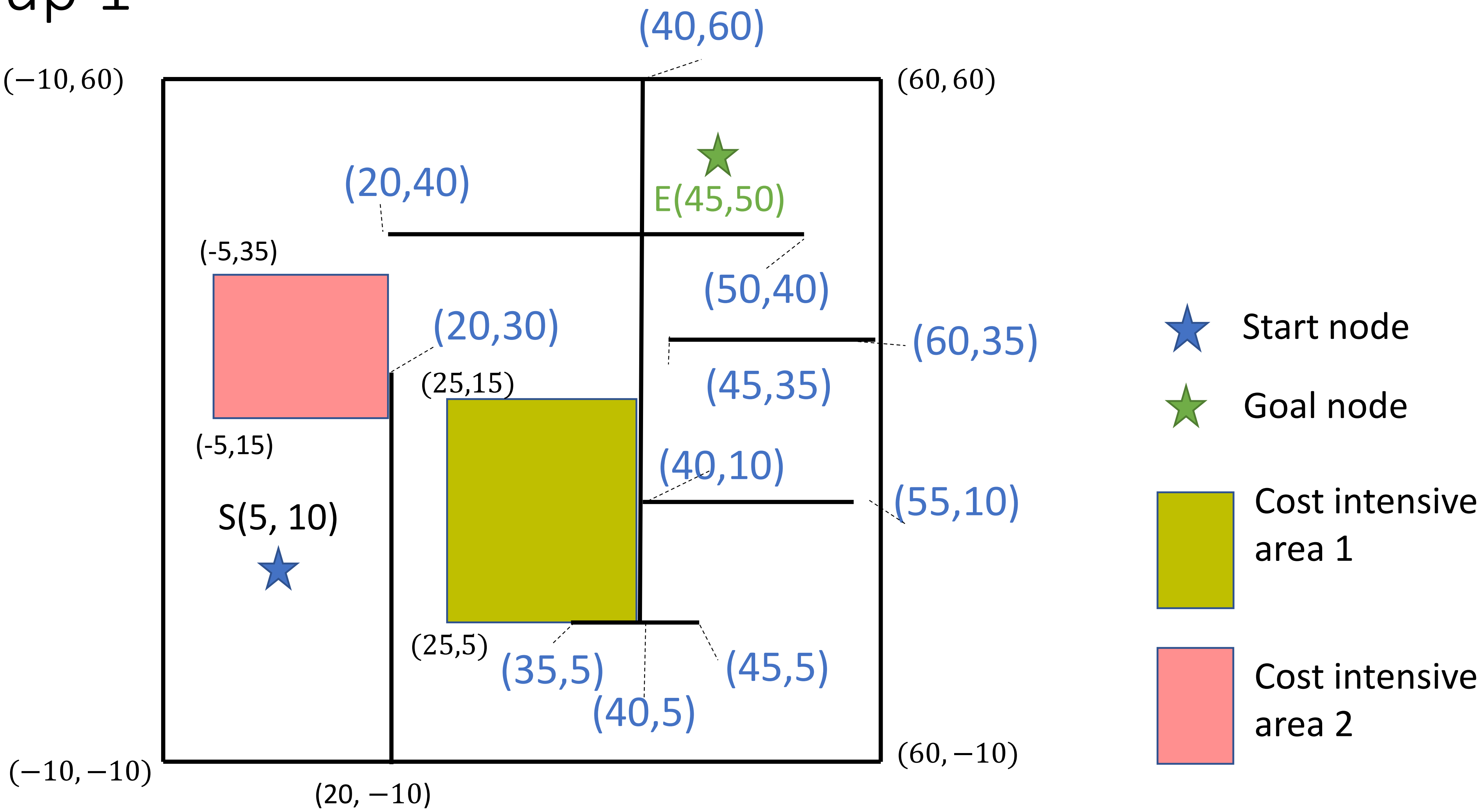
- C_c=fixed cost independent of time
- C_T=time related cost per minute of flight
- ΔF=trip fuel
- ΔT=trip time
- C = total trip cost

Group 1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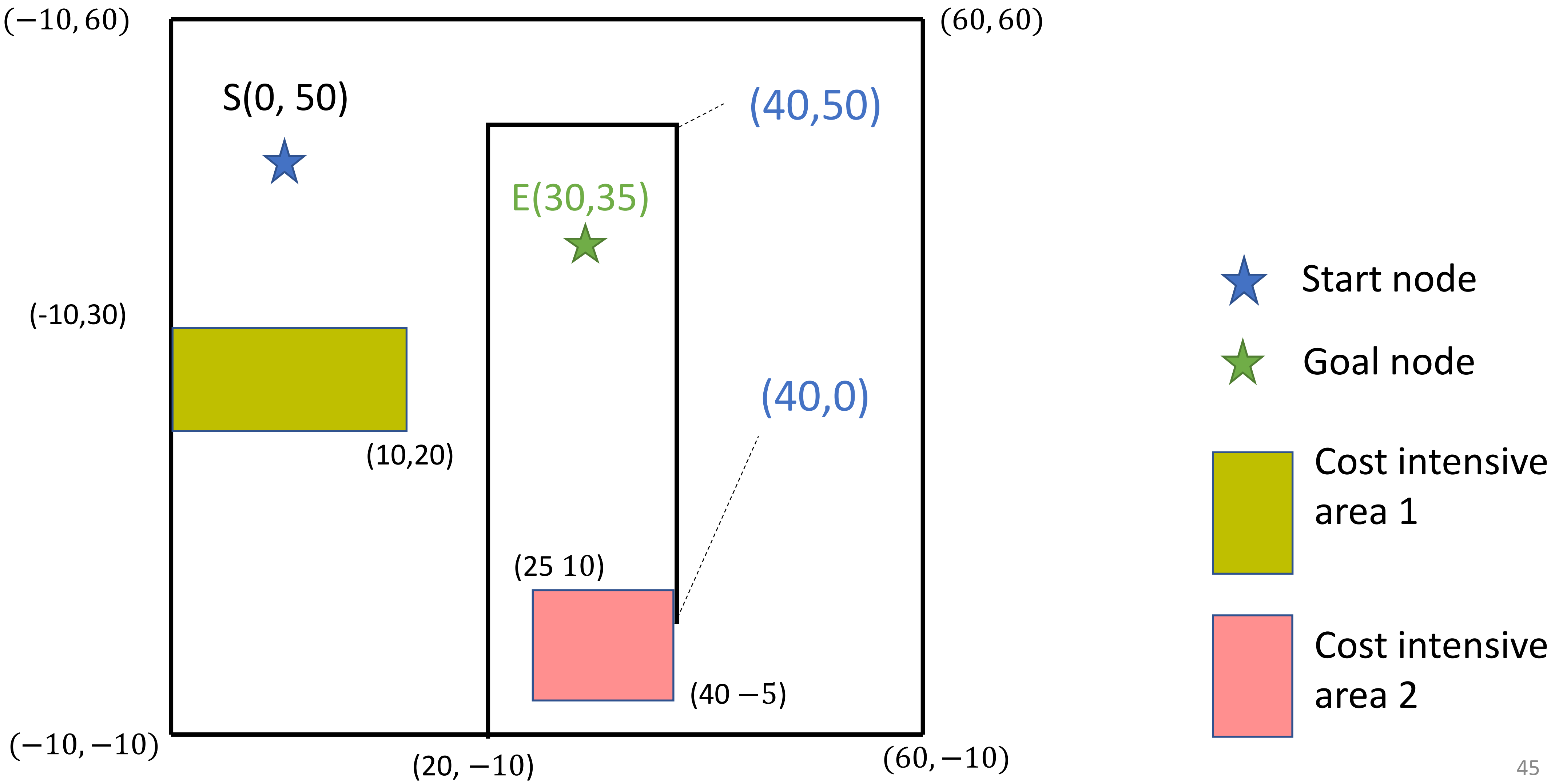
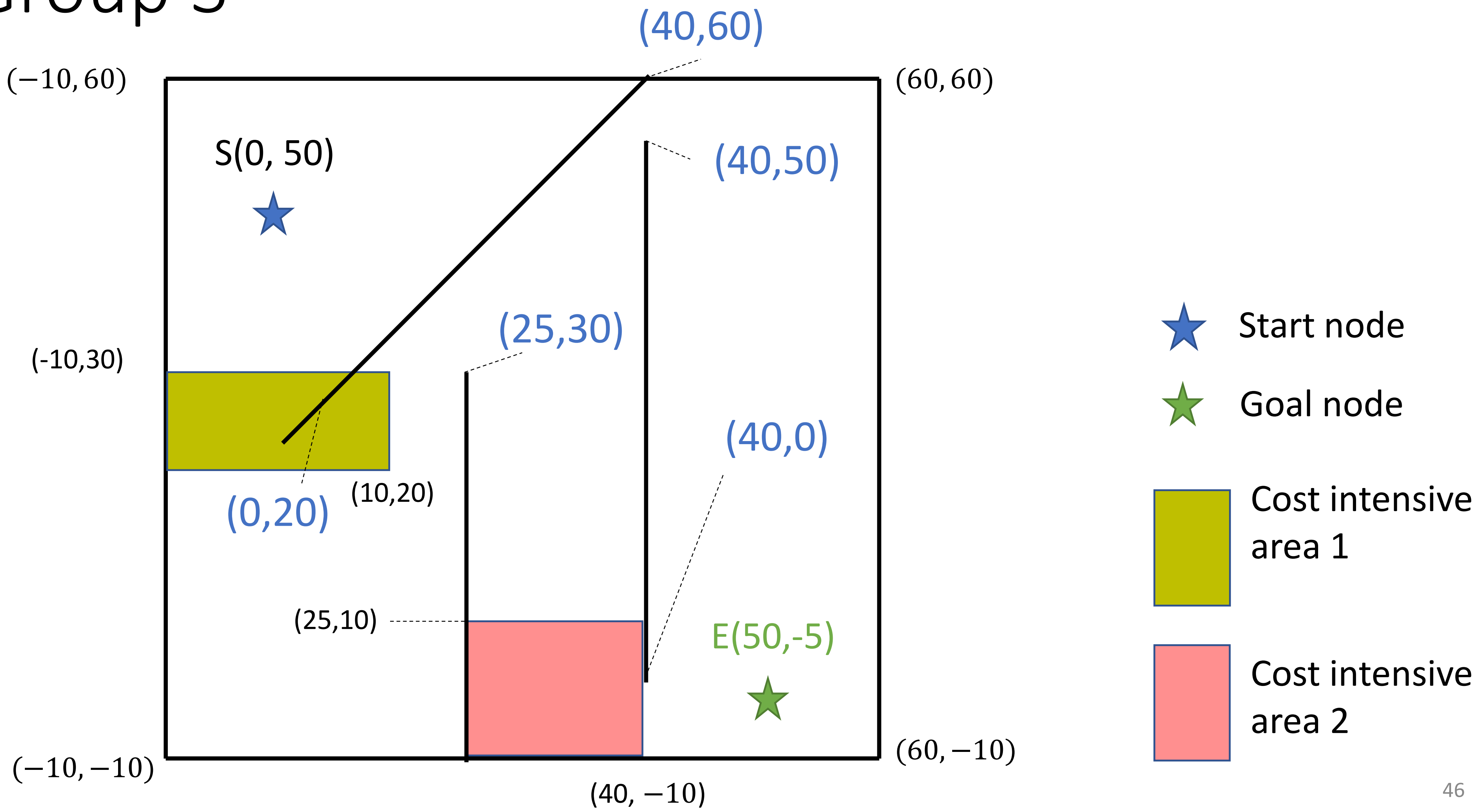
(−10, 60)
(60, 60)
E(45,50)
(20,40)
(-5,35)
(50,40)
(20,30)
(60,35)
(25,15)
(45,35)
(-5,15)
(40,10)
(55,10)
S(5, 10)
(25,5)
(35,5)
(45,5)
(40,5)
(−10, −10)
(20, −10)
(60, −10)
Start node
Goal node
Cost intensive area 1
Cost intensive area 2

Group 2

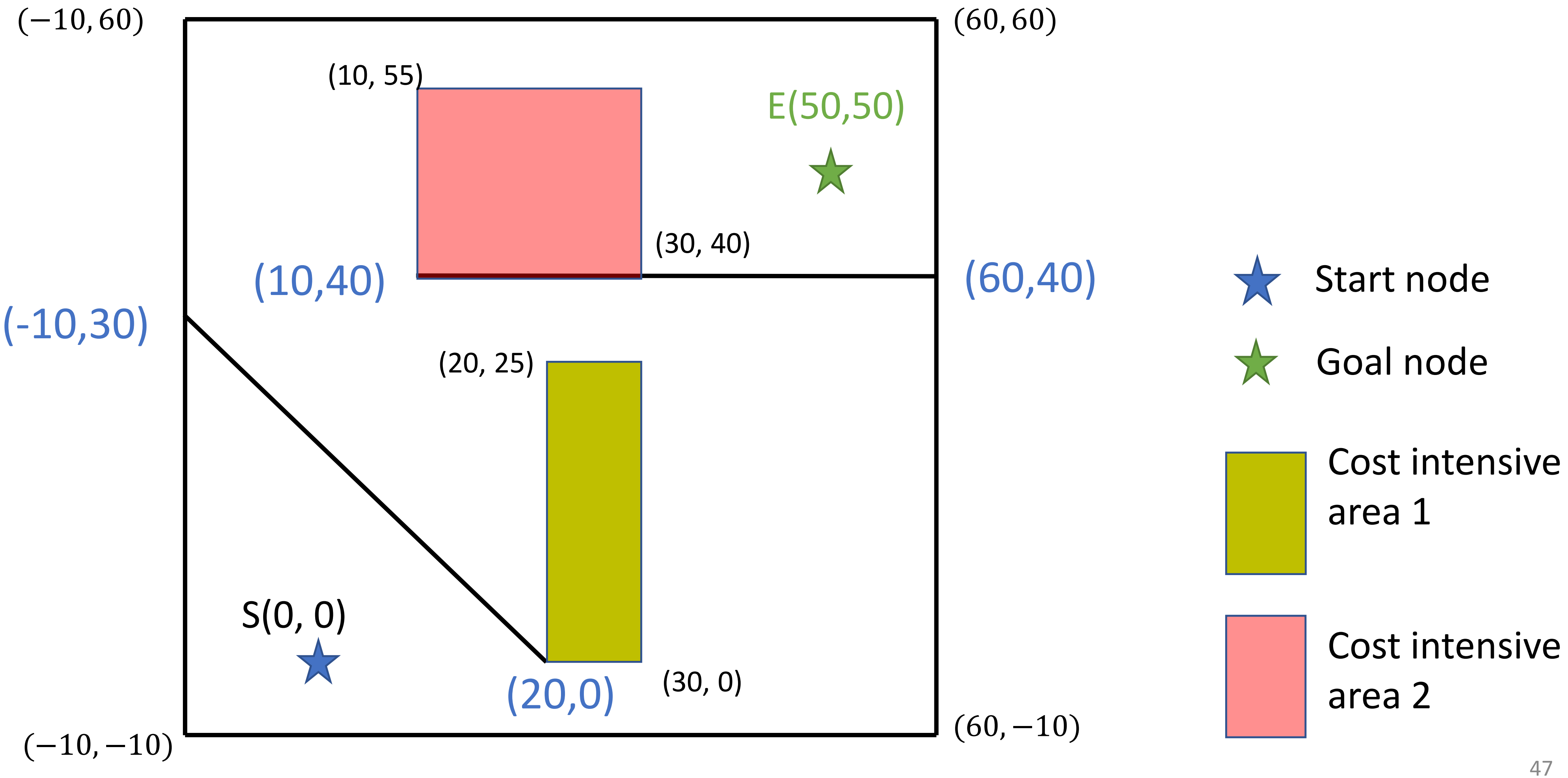


$(-10, 60)$
$(60, 60)$
S(0, 50)
(40,50)
E(30,35)
(-10,30)
(10,20)
(40,0)
(25 10)
(40 −5)
$(-10, -10)$
$(20, -10)$
$(60, -10)$
Start node
Goal node
Cost intensive area 1
Cost intensive area 2

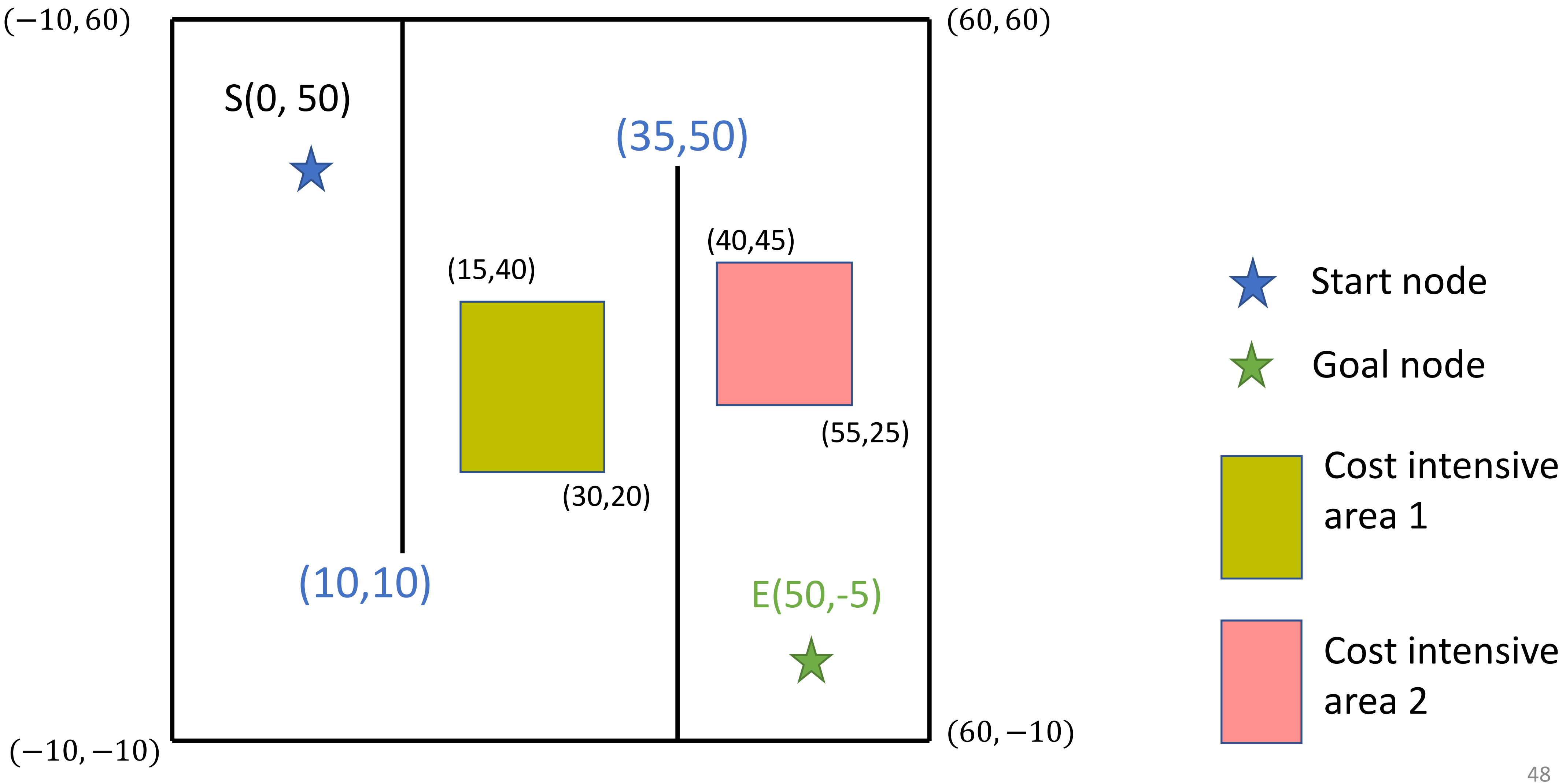
Group 3


(40,60)
(−10, 60)
(60, 60)
S(0, 50)
(40,50)
(25,30)
(-10,30)
(40,0)
(0,20)
(10,20)
(25,10)
E(50,-5)
(−10, −10)
(60, −10)
(40, −10)
Start node
Goal node
Cost intensive area 1
Cost intensive area 2

Group 4

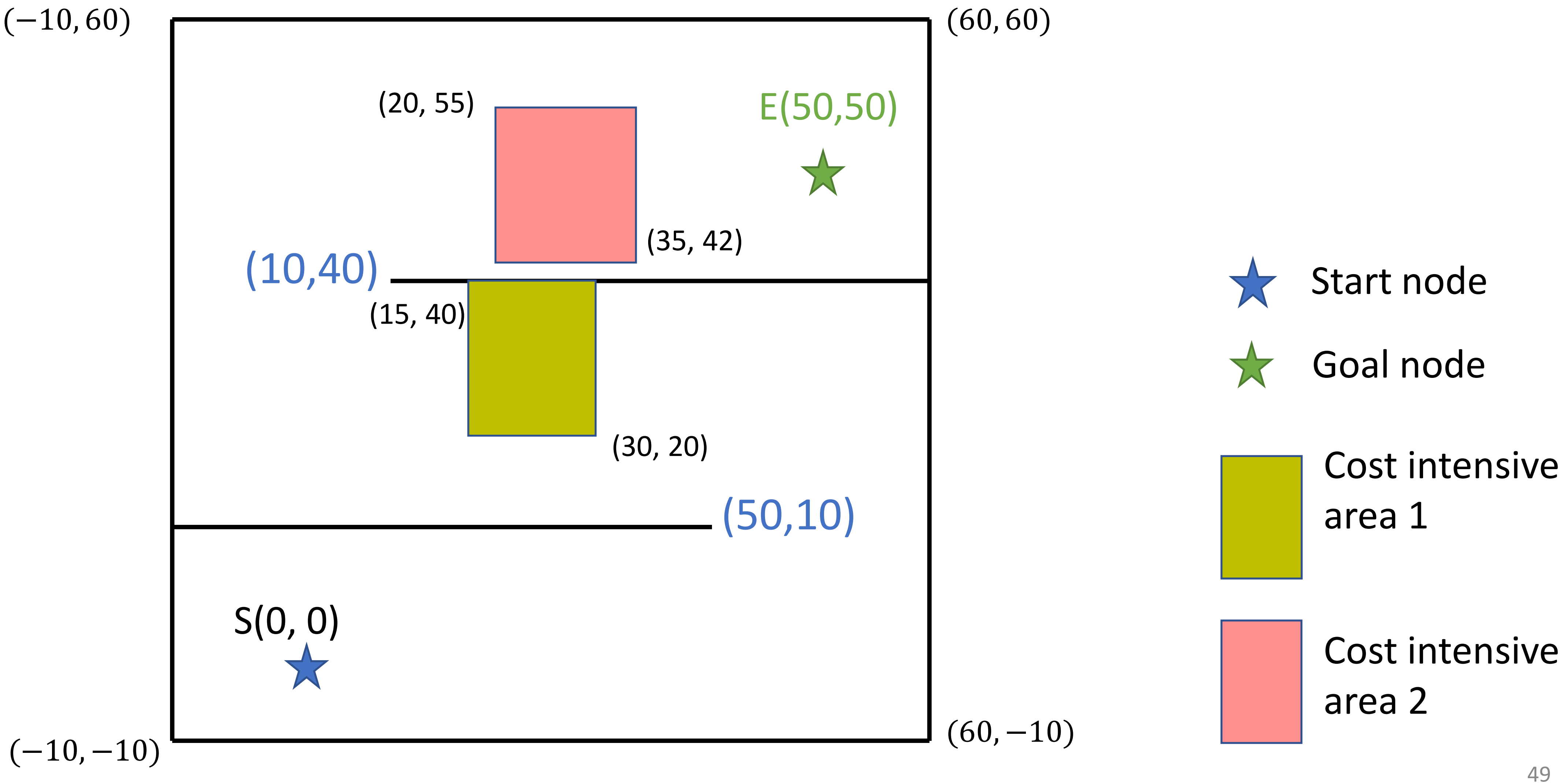

(−10, 60)
(60, 60)
(10, 55)
E(50,50)
(30, 40)
(10,40)
(60,40)
(-10,30)
(20, 25)
S(0, 0)
(20,0)
(30, 0)
(−10, −10)
(60, −10)
Start node
Goal node
Cost intensive area 1
Cost intensive area 2

Group 5



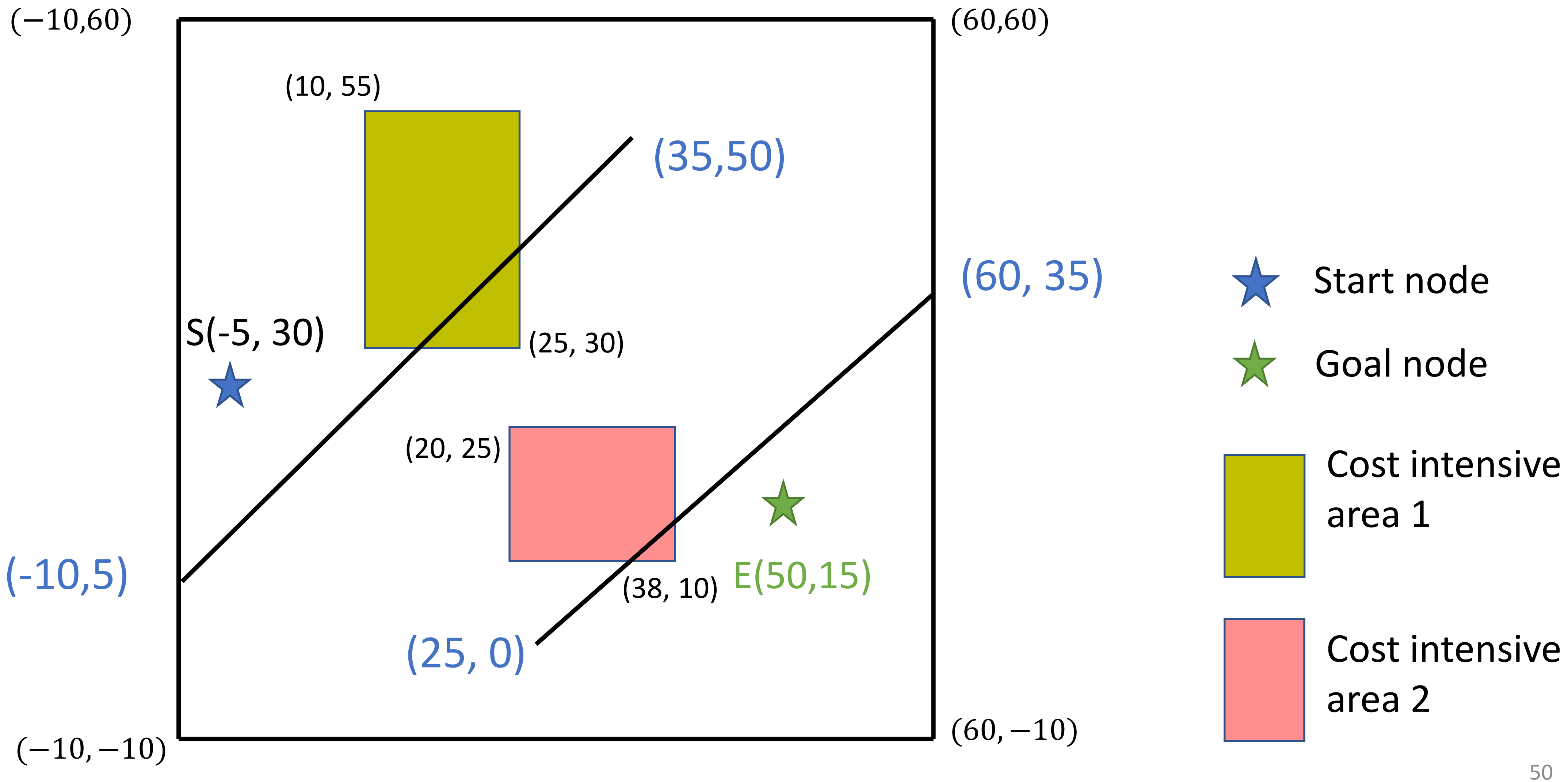
$(-10, 60)$
$(60, 60)$
S(0, 50)
(35,50)
(40,45)
(15,40)
(55,25)
(30,20)
(10,10)
E(50,-5)
$(-10, -10)$
$(60, -10)$
Start node
Goal node
Cost intensive area 1
Cost intensive area 2

Group 6



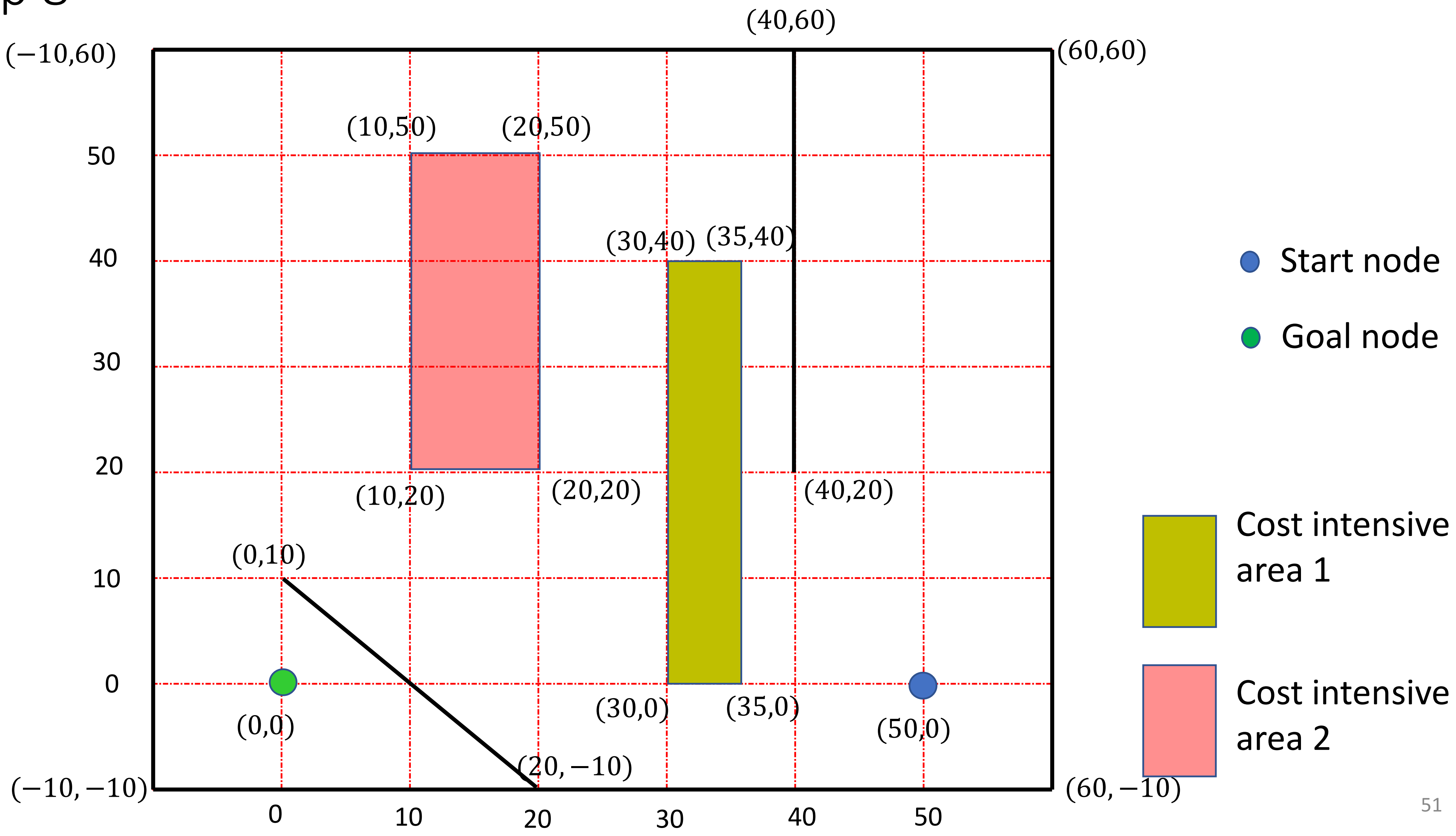
$(-10, 60)$
$(60, 60)$
(20, 55)
E(50,50)
(35, 42)
(10,40)
(15, 40)
(30, 20)
(50,10)
S(0, 0)
$(-10, -10)$
$(60, -10)$
Start node
Goal node
Cost intensive area 1
Cost intensive area 2

Group 7



$(-10,60)$
$(60,60)$
(10, 55)
(35,50)
(60, 35)
S(-5, 30)
(25, 30)
(20, 25)
(-10,5)
(38, 10)
E(50,15)
(25, 0)
$(-10,-10)$
$(60,-10)$
Start node
Goal node
Cost intensive area 1
Cost intensive area 2

Group 8



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(30,40)
(35,40)
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(10,20)
(20,20)
(40,20)
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10
0
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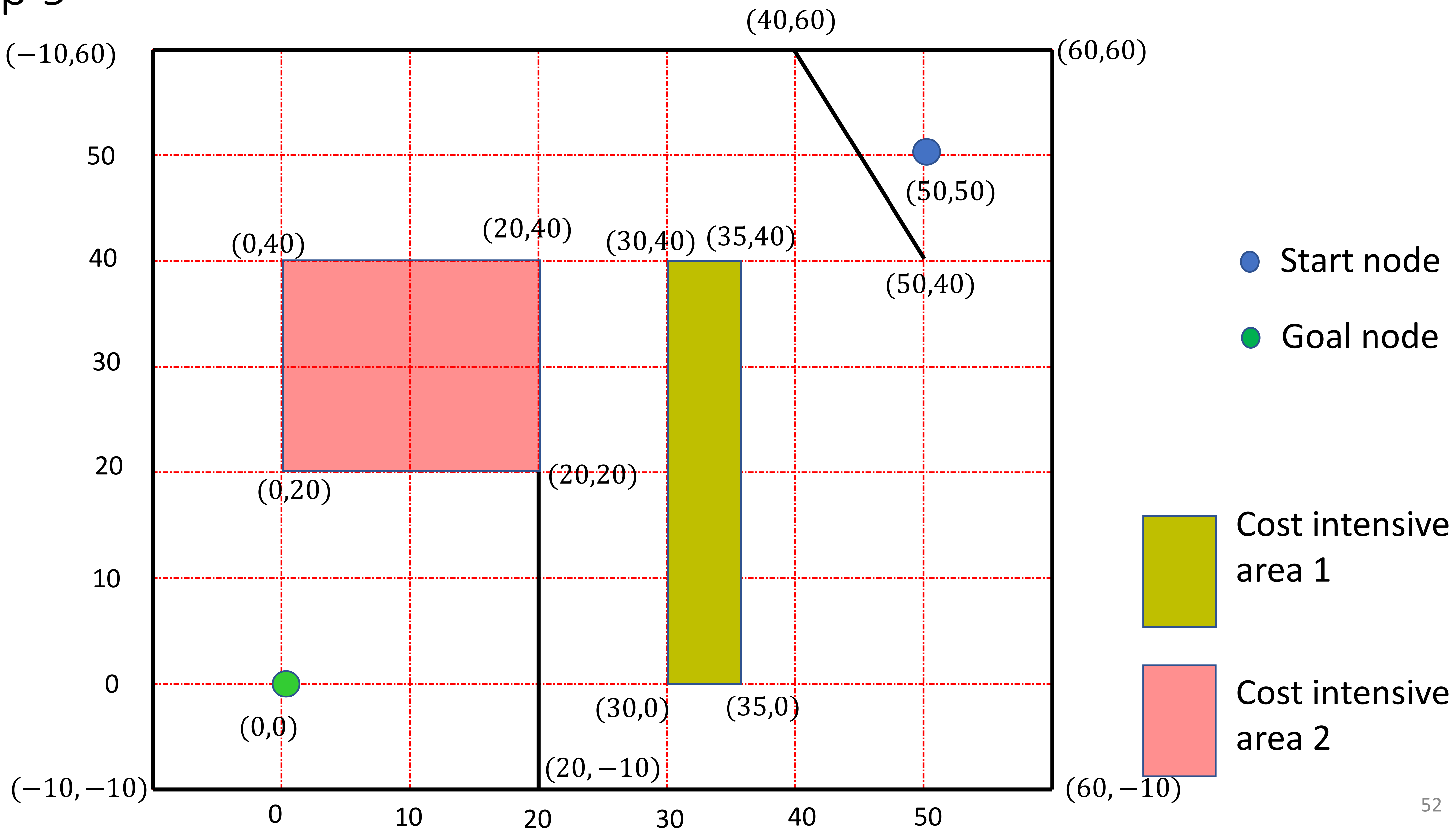
(30,0)
(35,0)
(50,0)
(20, −10)
(−10, −10)
(60, −10)
0
10
20
30
40
50
Start node
Goal node
Cost intensive area 1
Cost intensive area 2

Group 9



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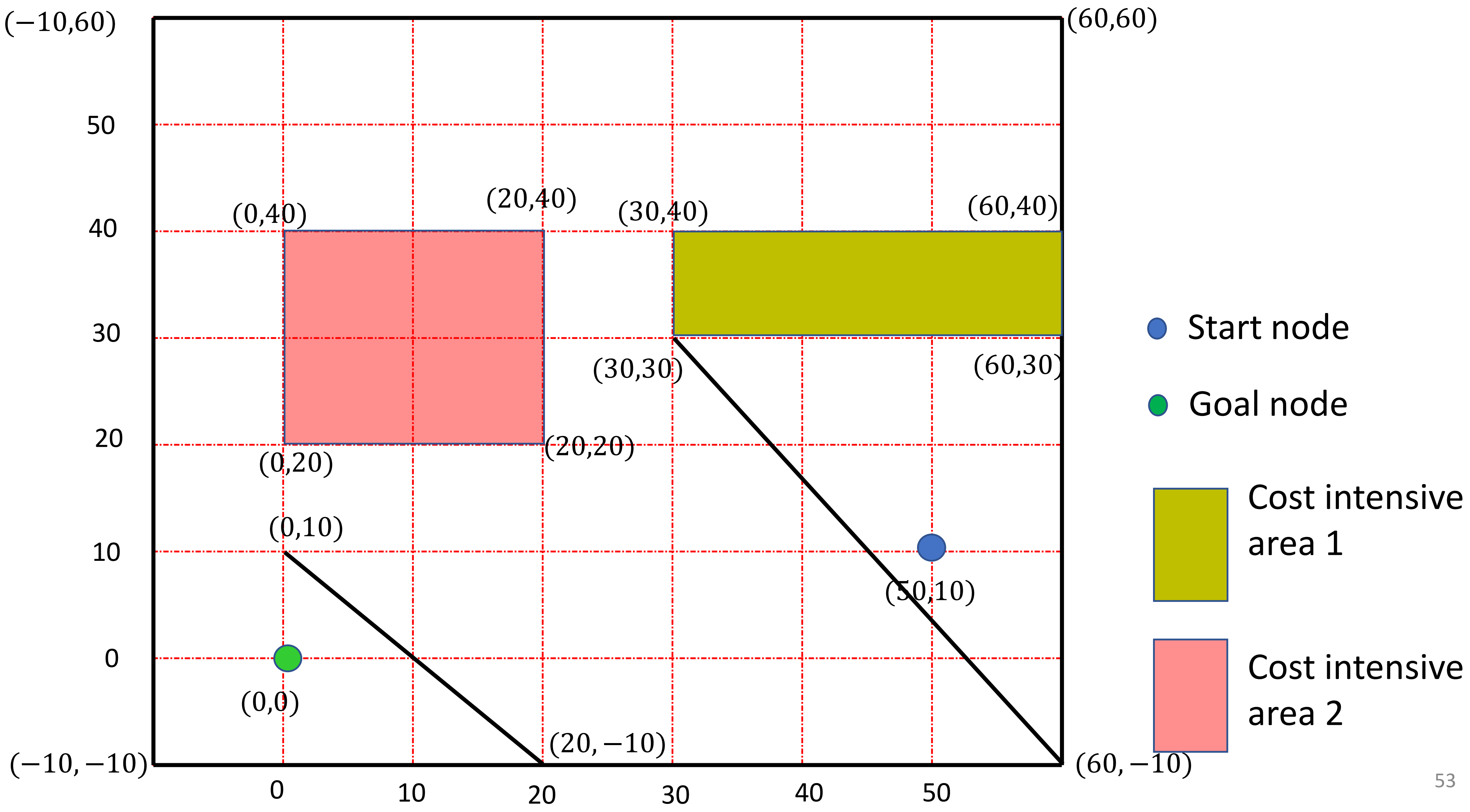
(50,50)
(20,40)
(0,40)
(30,40)
(35,40)
40
(50,40)
30
20
(20,20)
(0,20)
10
0
(0,0)
(30,0)
(35,0)
(20, −10)
(−10, −10)
(60, −10)
0
10
20
30
40
50
Start node
Goal node
Cost intensive area 1
Cost intensive area 2

Group 10



(−10,60)
(60,60)
50
40
30
20
10
0
(0,40)
(20,40)
(30,40)
(60,40)
(30,30)
(60,30)
(0,20)
(20,20)
(0,10)
(50,10)
(0,0)
(20, −10)
(−10, −10)
(60, −10)
0
10
20
30
40
50
Start node
Goal node
Cost intensive area 1
Cost intensive area 2

Task 1 Scenarios

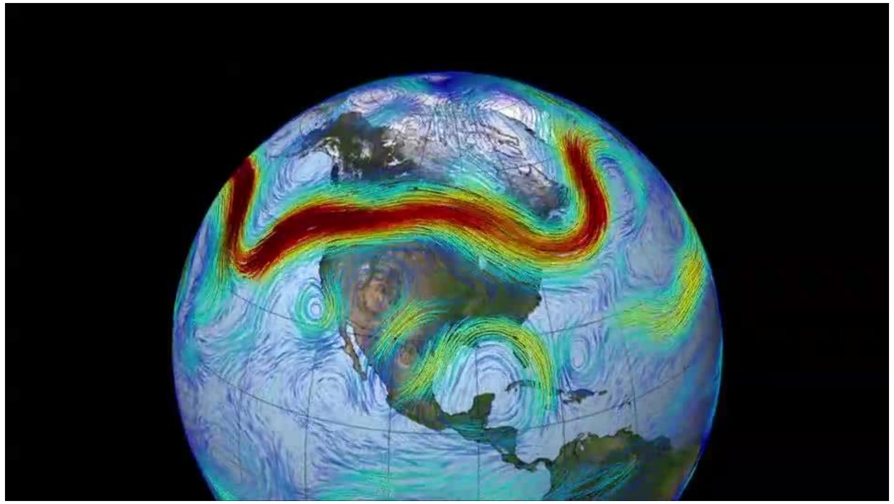
1. Scenario 1
    1. 3000 Passengers need to travel this week from the start to the destination
    2. 12 flights maximum for one week
    3. Time cost = medium and Fuel cost = 0.76 $/kg
2. Scenario 2
    1. 1250 Passengers need to travel within this month from the start to the destination
    2. 5 flights maximum for one week
    3. Time cost = high and Fuel cost = 0.88 $/kg
3. Scenario 3
    1. 2500 Passengers need to travel within this week from the start to the destination
    2. 25 flights maximum for one week
    3. Time cost = low and Fuel cost = 0.95 $/kg

Design a new cost area that can reduce the cost of the route.

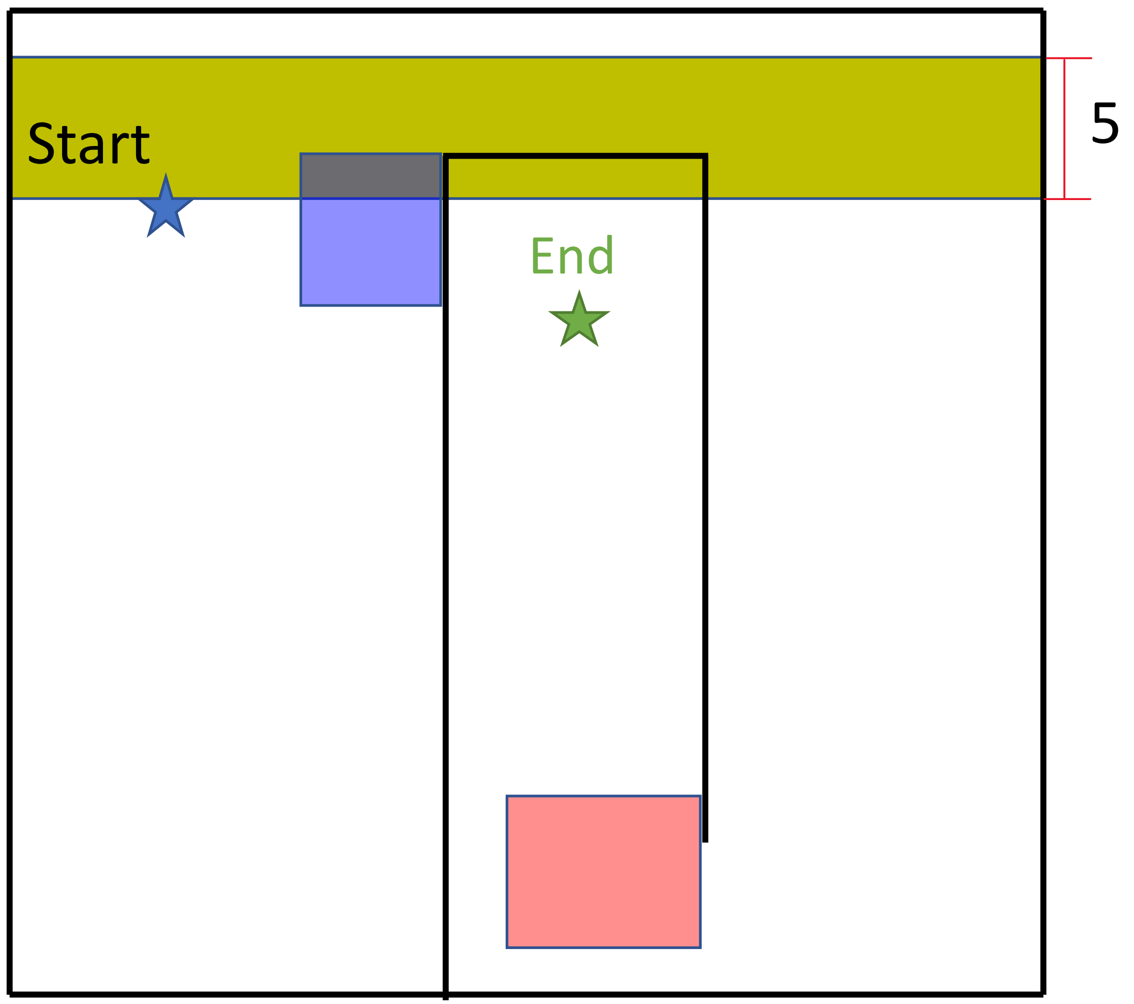
Task 2

Task 2

- There are certain areas where aircrafts could consume relatively less fuel (Jet stream)
- On the other hand, there are cost intensive areas (like the ones you create in task 1)
- Recreate a jet stream that could benefit your flight route the most



Jet stream example (you decide the location)



- Use Scenario 1 of task 1 as the background
- Find the best place to set your minus-cost-area (jet stream) in your group challenge.
- Cost along the jet stream is reduced by 5% *[https://www.theengineer.co.uk/jet-stream-commercial-airlines-reading-university-emissions/]*
- The area of the jet stream must span across the map laterally and span **5** units vertically (Yellow area)
- Again, using the program to do the calculation would grant you more bonus marks!

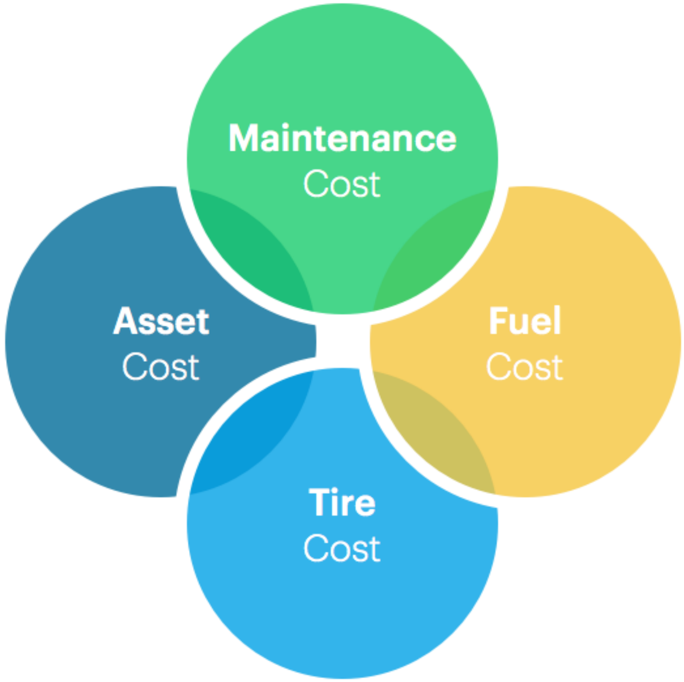
Design a new Aircraft Model that achieve minimum cost for the challenge assigned to your group

(Path planning programme not necessary in this task)

Task 3

Designing an Aircraft

- In real life, aircrafts are designed based on industry needs:
- A380 for large global transport hubs
- Design a new aircraft by finding out its parameters based on the restrictions



Task 3

- Rules and Restrictions:
  - Design a new aircraft to best fit the Scenario 1 in task 1
  - Consider only cruise time of the flight
  - Also design the passenger capacity of the aircraft, for each 50 passenger (min 100 to max 450) increase time cost by 2 (Base C_T = 12)
  - The base design is a twin-engine aircraft, if capacity >= 300, you must switch to a 4-engine aircraft
  - C_C= 2000 for twin-engine aircrafts, 2500 for 4-engine aircrafts
  - Each engine consumes fuel at 20kg/min
  - Follow the following equations and materials on the next slides to design your aircraft:

- Task 3 requires:
  - A name for your aircraft
  - Passenger capacity
  - Engine count
  - Detailed calculation of all operating costs (Follow the equation)
  - Bonus: Carefully study the rules and restrictions, try and explain the reason / evidence behind them (Open ended)

$$\mathrm{C} = C_F \cdot \Delta F + C_T \cdot \Delta T + C_c$$

- C_F=cost of fuel per kg
- C_T=time related cost per minute of flight
- C_c=fixed cost independent of time
- C_T=time related cost per minute of flight
- ΔF=total trip fuel
- ΔT=total trip time
- C = total cost per trip

Fuel Cost *https://www.iata.org/en/publications/economics/fuel-monitor/*

Fuel Price Analysis

The jet fuel price ended last week up 5.7% at $111.7/bbl:

4 February 2022	Share in World Index	cts/gal	$/bbl	$/mt	Index Value 2000 = 100	vs. 1 week ago	vs. 1 month ago	vs.1 yr ago
Jet Fuel Price	100%	266.02	111.73	882.30	305.42	5.7%	14.7%	73.7%
Asia & Oceania	22%	251.62	105.68	834.89	301.96	3.5%	14.8%	67.2%
Europe & CIS	28%	266.20	111.80	882.13	301.23	4.8%	14.2%	75.2%
Middle East & Africa	7%	254.67	106.96	844.55	319.42	4.0%	15.4%	71.5%
North America	39%	275.14	115.56	912.90	307.21	7.7%	14.7%	76.4%
Latin & Central America	4%	274.91	115.46	912.17	319.85	7.2%	16.3%	75.5%