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

Third Week

Dr Li-Ta Hsu and Dr Kam Hung NG
Assisted by
Miss Hiu Yi HO (Queenie), Miss Yan Tung LEUNG (Nikki)

Lecturer's Information

- **Instructor**: Dr Li-Ta HSU
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- **Phone**: 3400-8061
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- Office Hour: by appointment

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

Li-Ta HSU

1985.08 – Born in a fish farmer family in Tainan, Taiwan

2003.06 – Graduated from Kang Ming Senior High School, Taiwan

2007.06 – Bachelor of NCKU Department of Aeronautics and Astronautics (DAA), Taiwan

2010.09 – Ph.D. Candidate of NCKU DAA, Taiwan

2012.02 – Visiting Researcher in University College London, UK

2012.06 – Part-time Consultant for Spirent, UK

2013.07 – Visiting Researcher in Tokyo Marine University, Japan

2013.12 – Ph.D. of NCKU DAA, Taiwan

2014.04 – Postdoctoral Researcher in the University of Tokyo , Japan

2017.05 – Assistant Professor in AAE of PolyU, Hong Kong

2021.07 – Associate Professor in AAE of PolyU, Hong Kong

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!

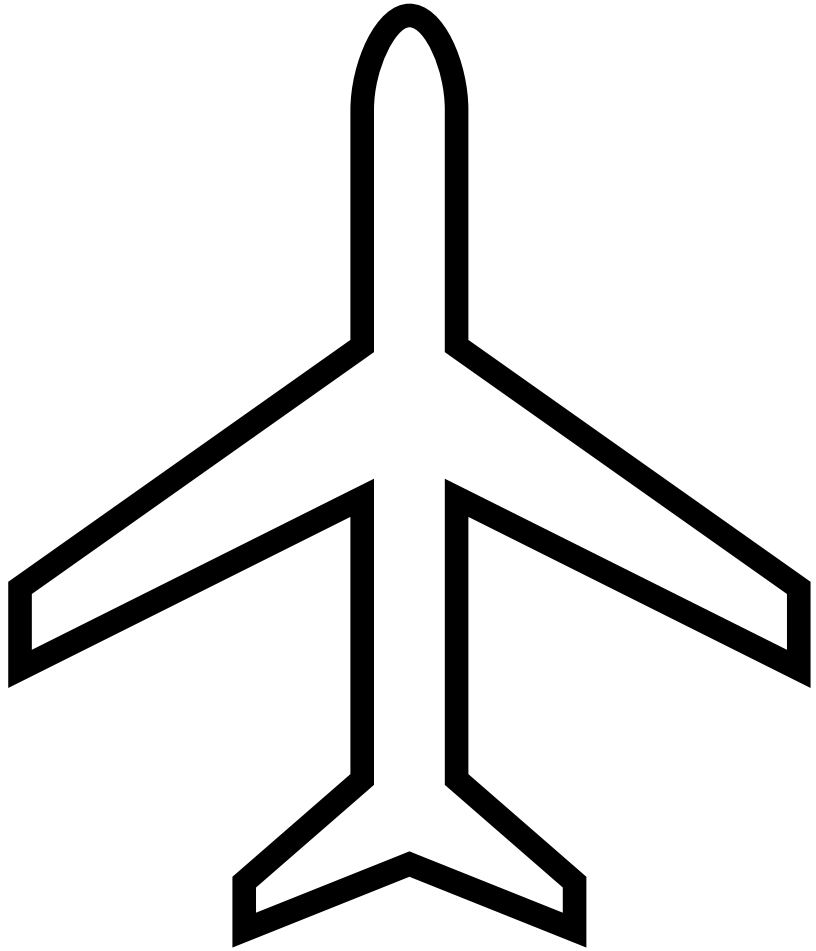
- Keep an open mind—enter the classroom dialogue with the expectation of learning something new. Look forward to learning about–and being challenged by–ideas, questions, and points of view that are different than your own.
- Arrive on time to the class and finish the class on time

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 3 Content

1. Project Compulsory Tasks
2. Project Additional Tasks (Optional)
3. GitHub Readme tutorial



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

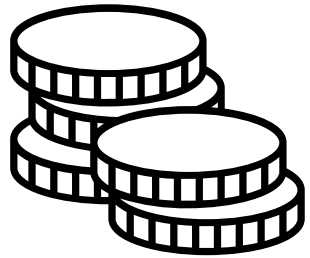
- C_F=cost of fuel per kg
- C_T=time related cost per minute of flight
- C_c=fixed cost independent of time
- C_T=time related cost per minute of flight
- ΔF=trip fuel
- ΔT=trip time
- C = total trip cost

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
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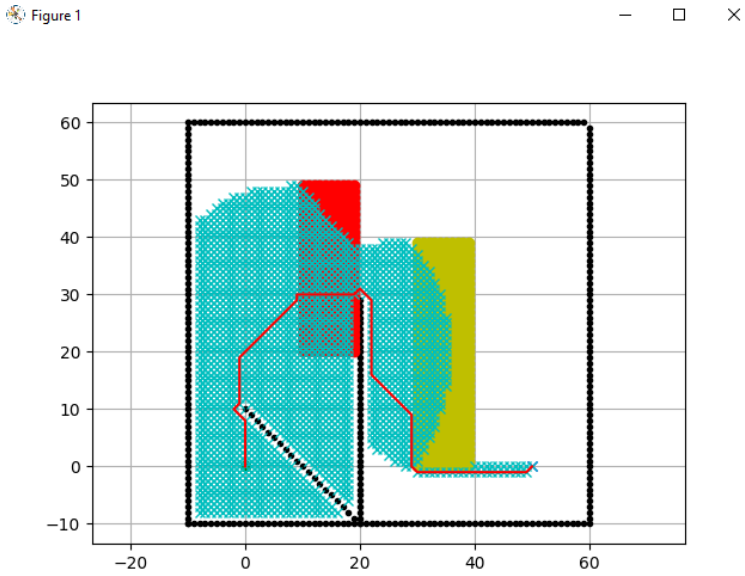
Task 1 Example (Step-by-step)

- 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 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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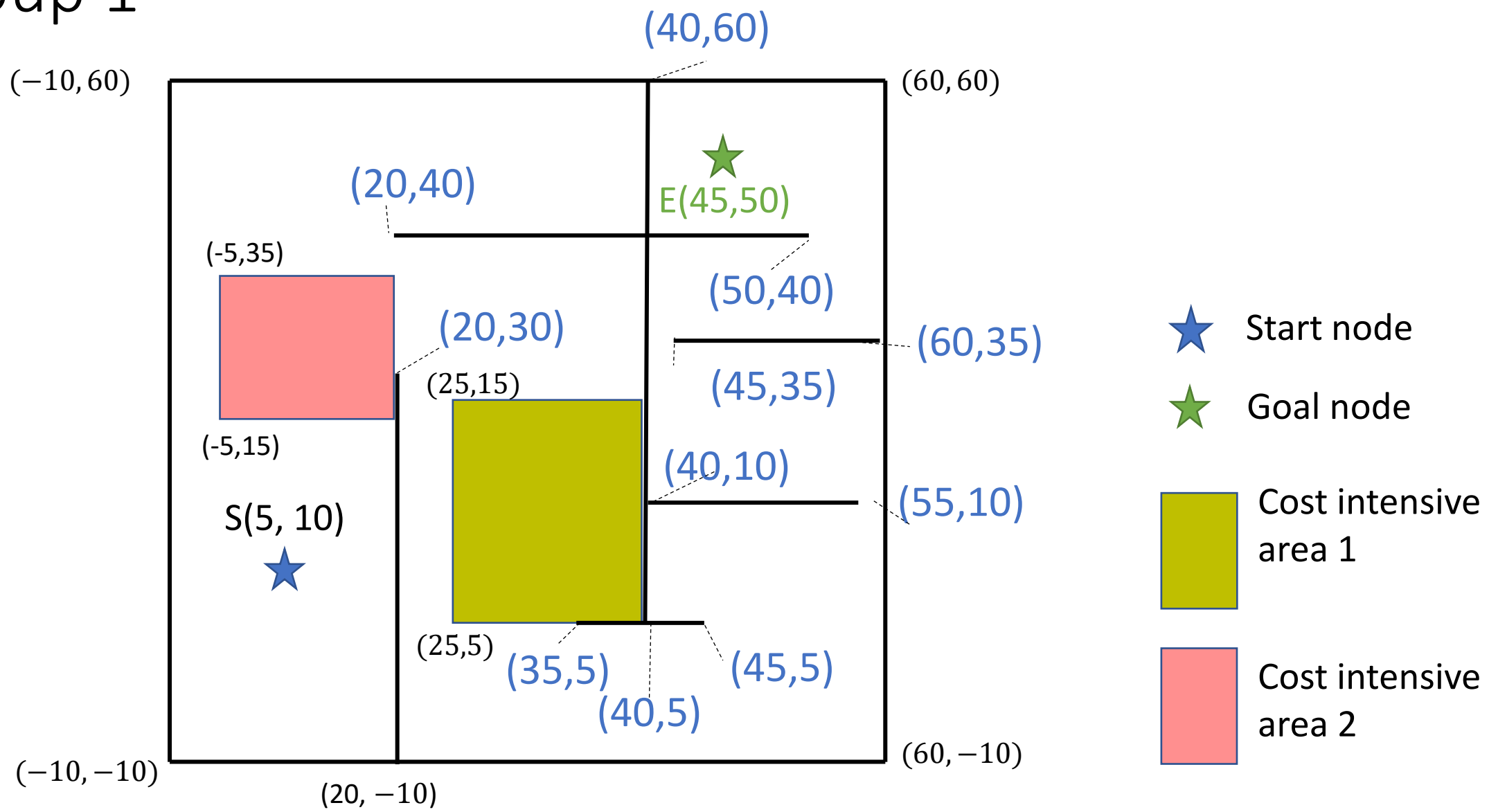
- C = total trip cost

Group 1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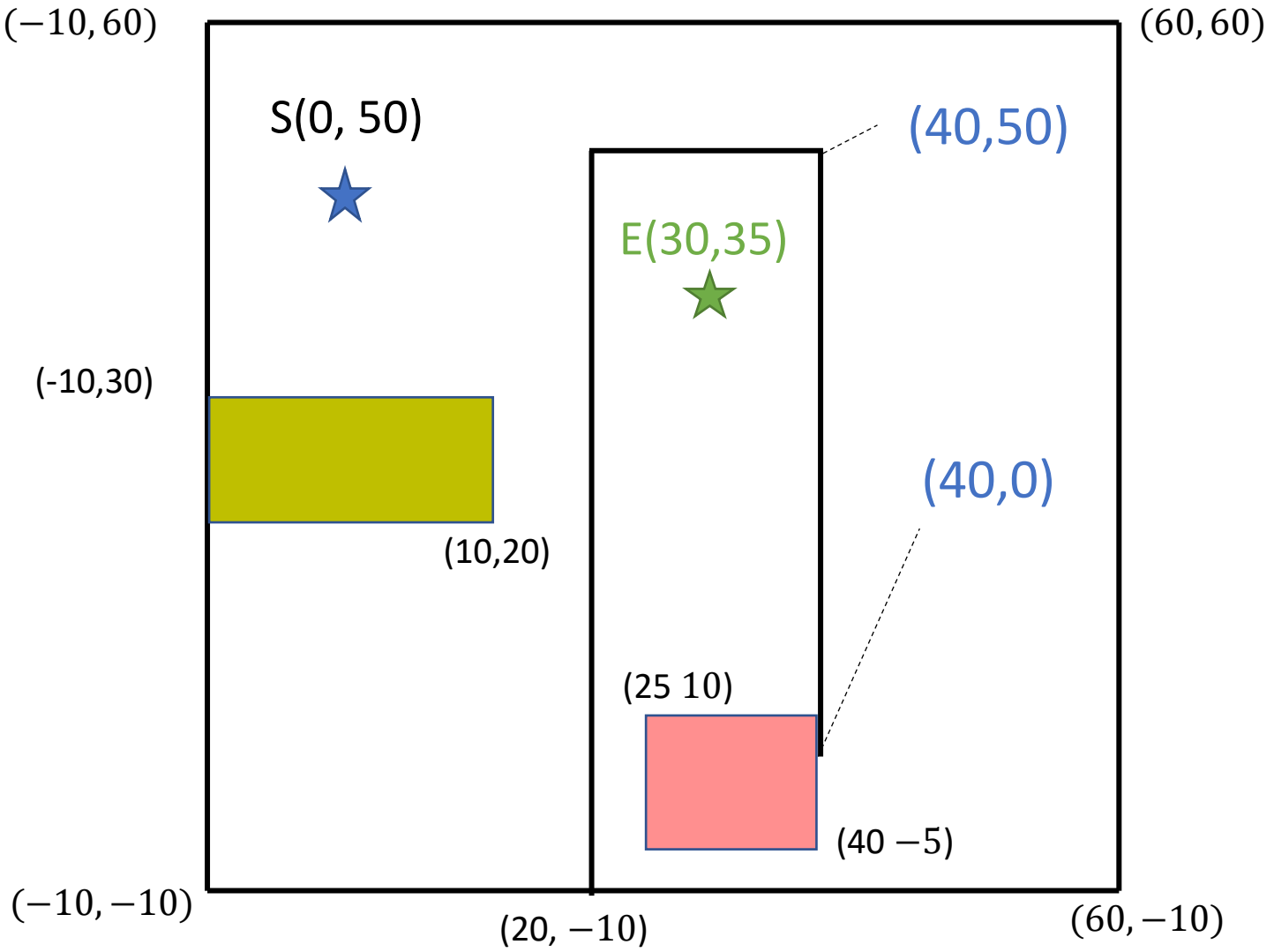
Start node
Goal node
Cost intensive area 1
Cost intensive area 2

Group 2



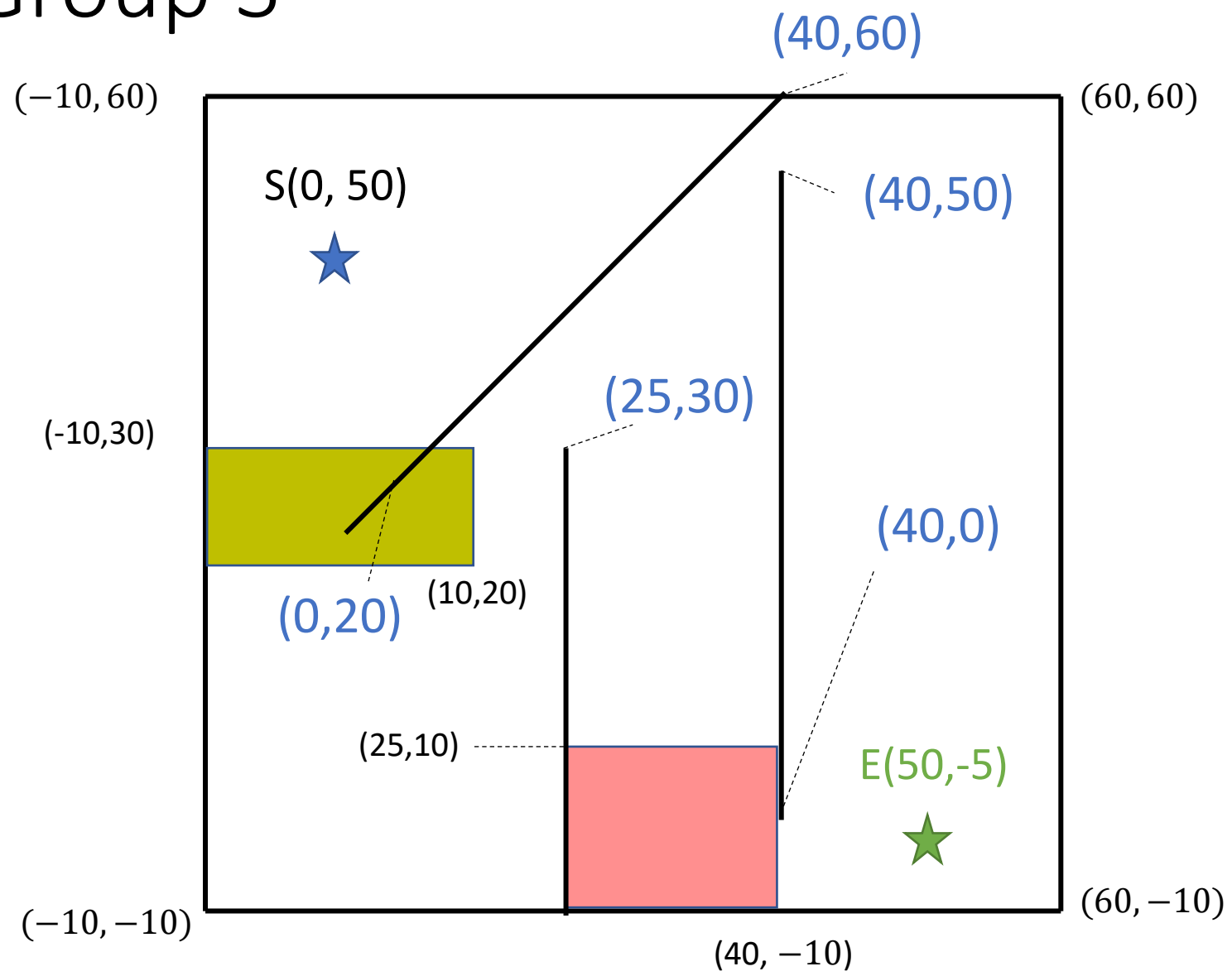
Start node

Goal node

Cost intensive area 1

Cost intensive area 2

Group 3



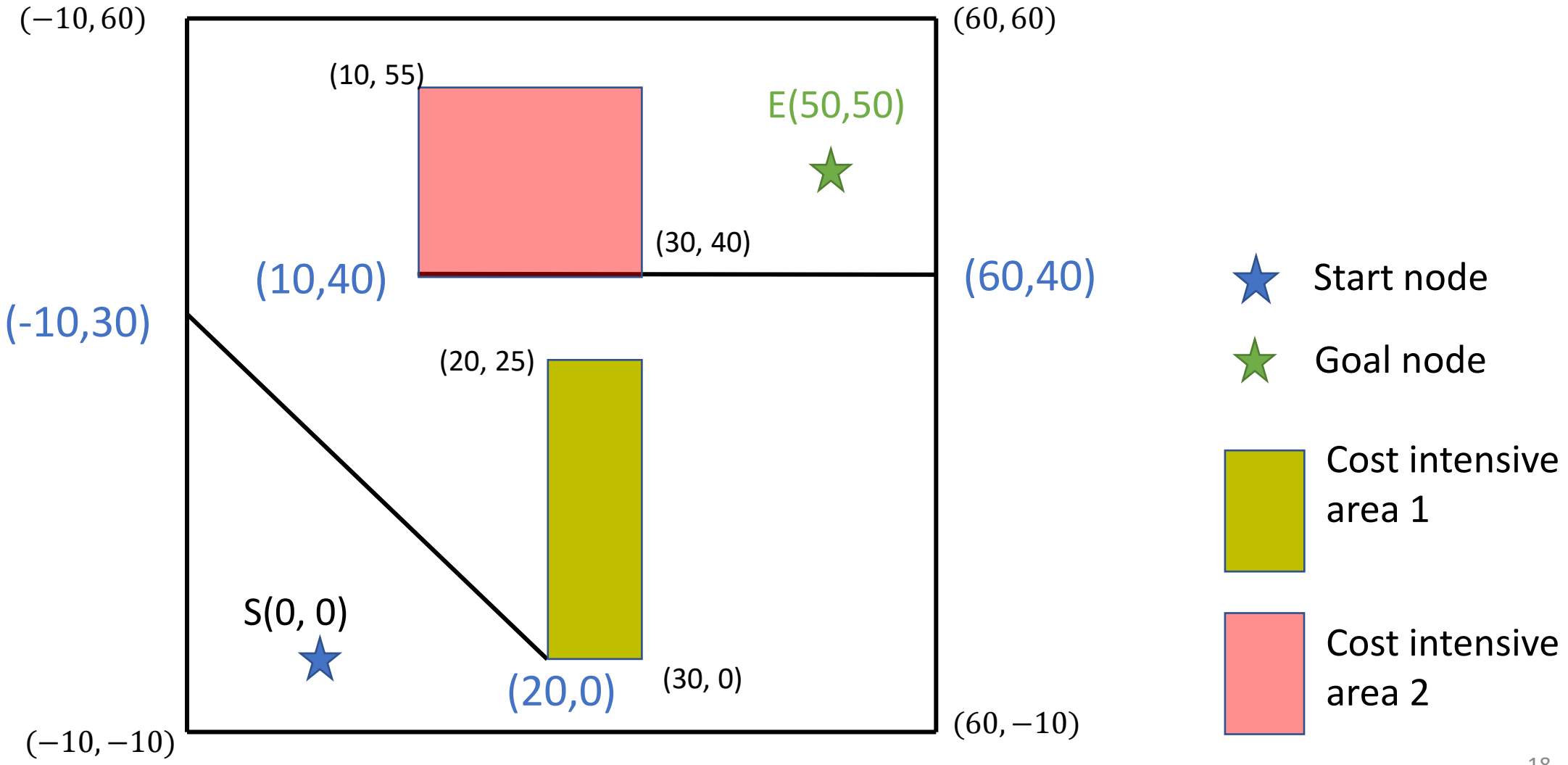
Start node

Goal node

Cost intensive area 1

Cost intensive area 2

Group 4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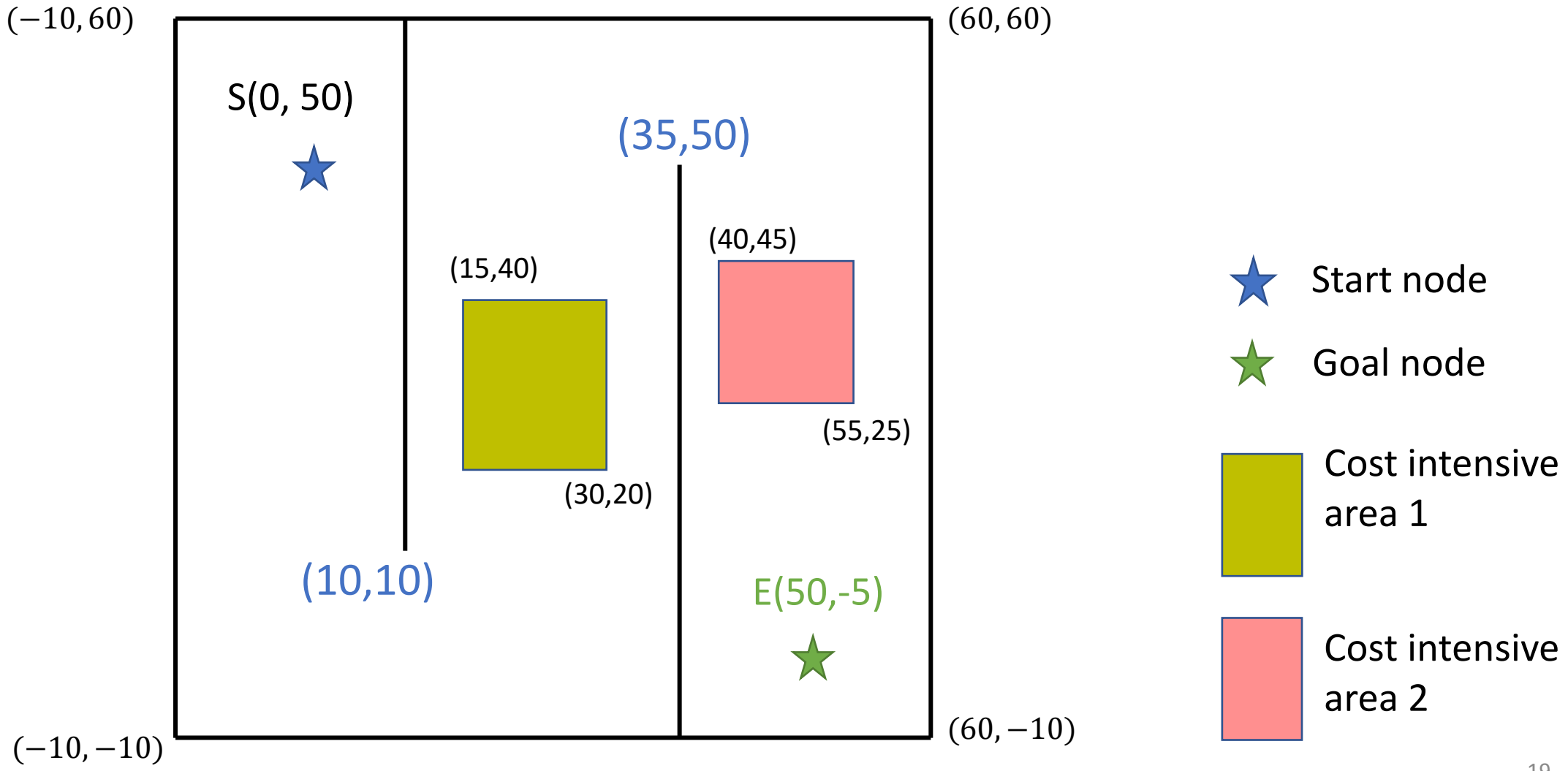
Start node
Goal node
Cost intensive area 1
Cost intensive area 2

Group 5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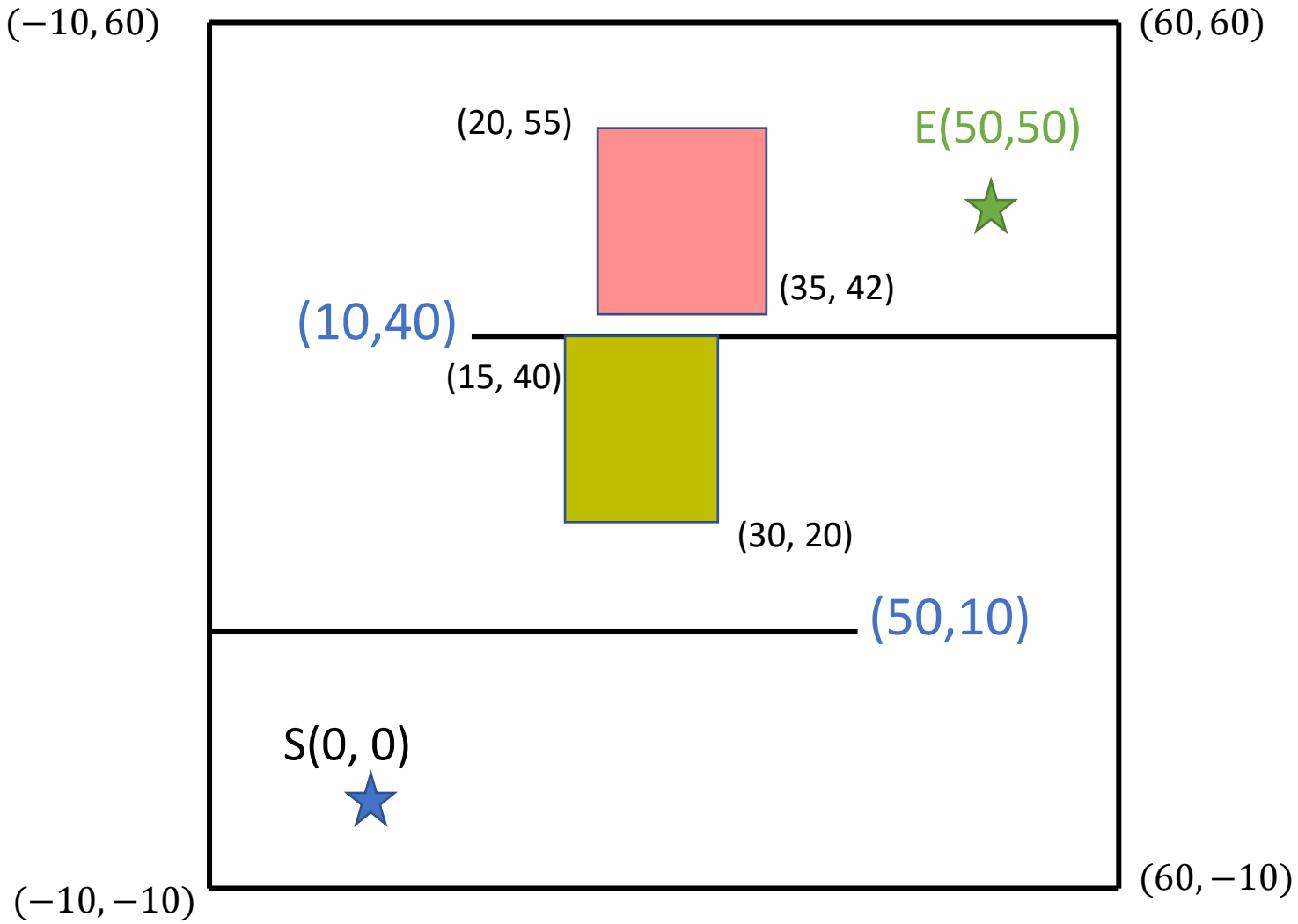
Start node
Goal node
Cost intensive area 1
Cost intensive area 2

Group 6



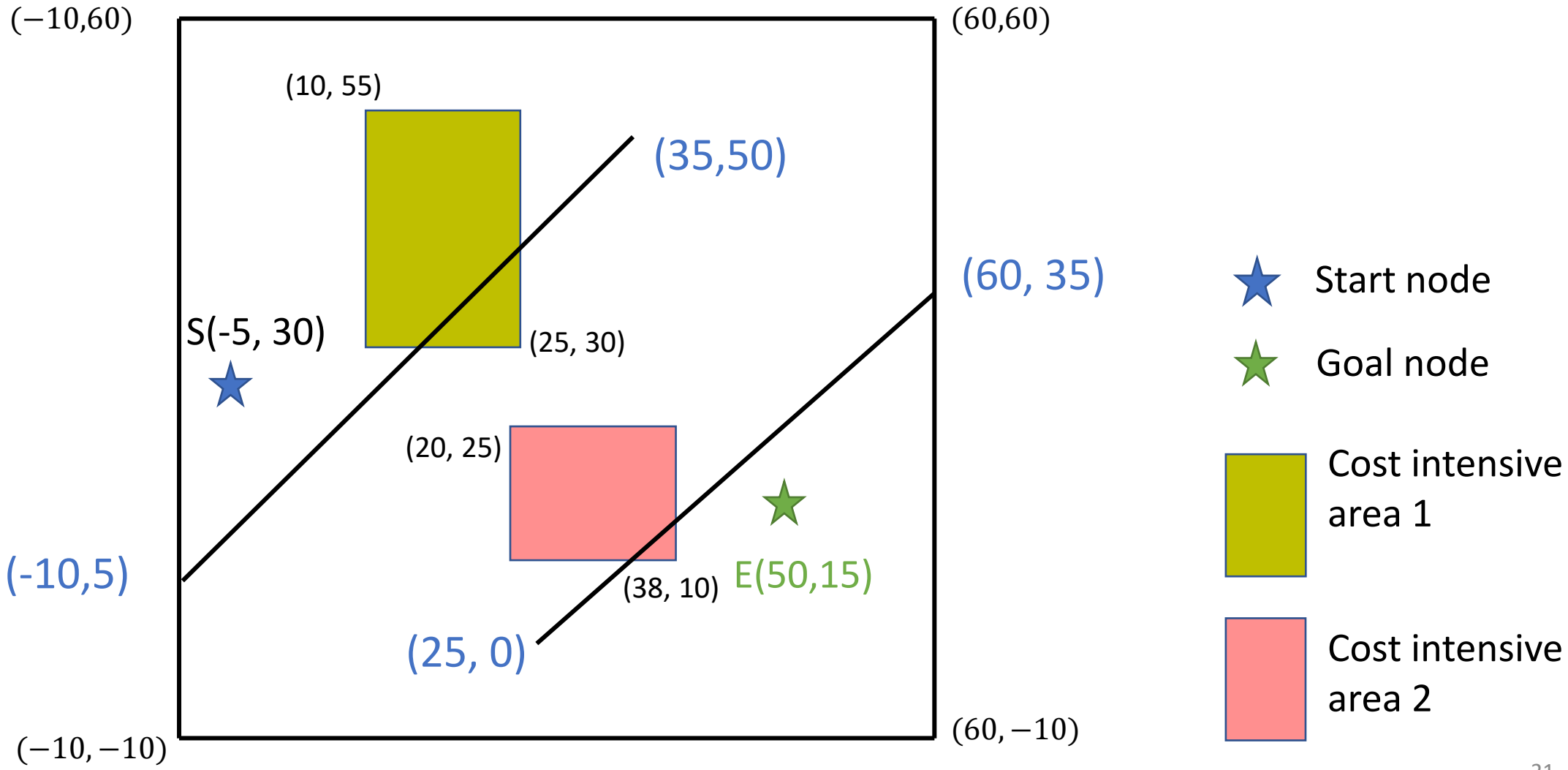
Start node

Goal node

Cost intensive area 1

Cost intensive area 2

Group 7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S(-5, 30)
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(38, 10)
E(50,15)
(25, 0)
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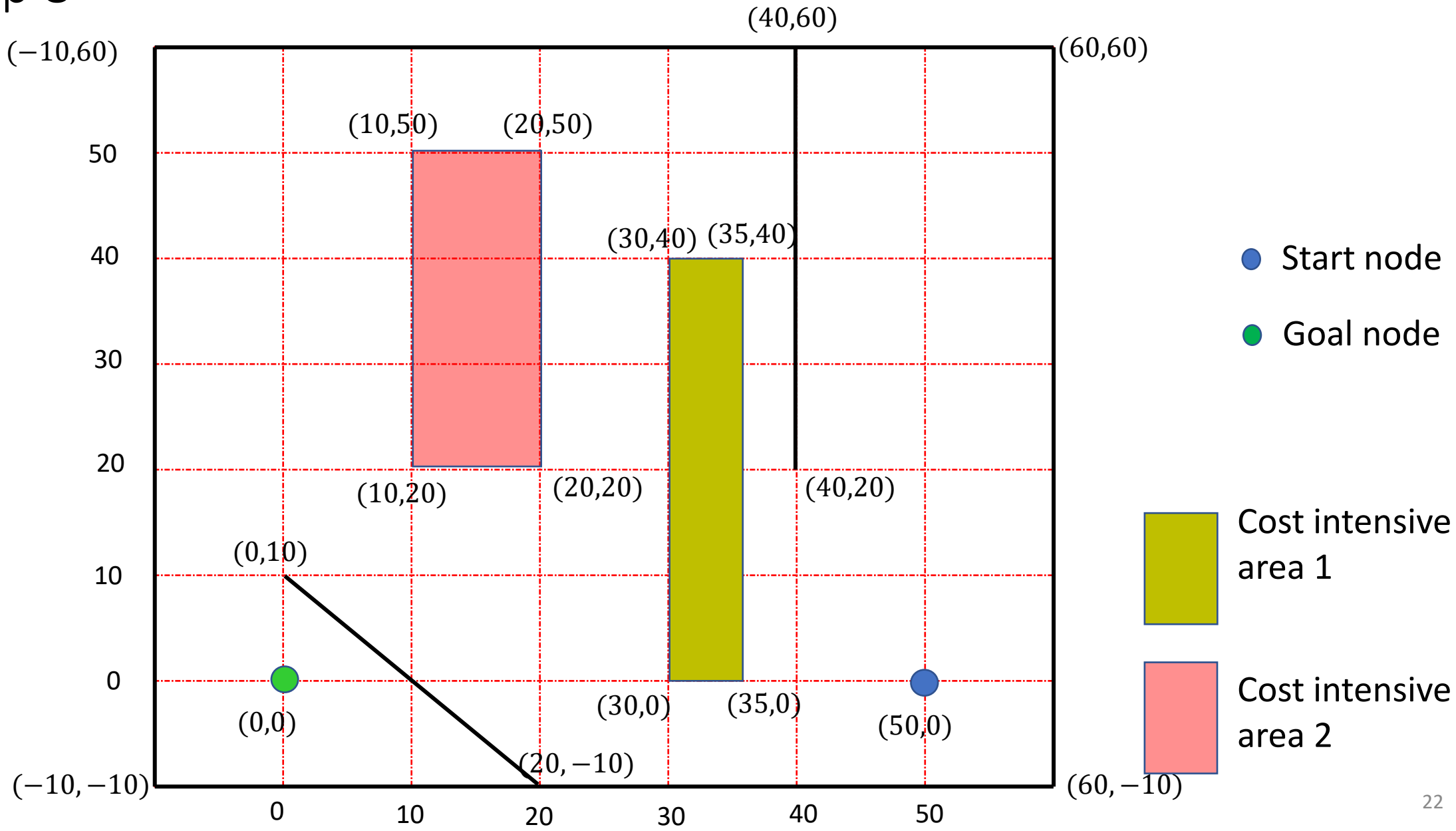
Start node
Goal node
Cost intensive area 1
Cost intensive area 2

Group 8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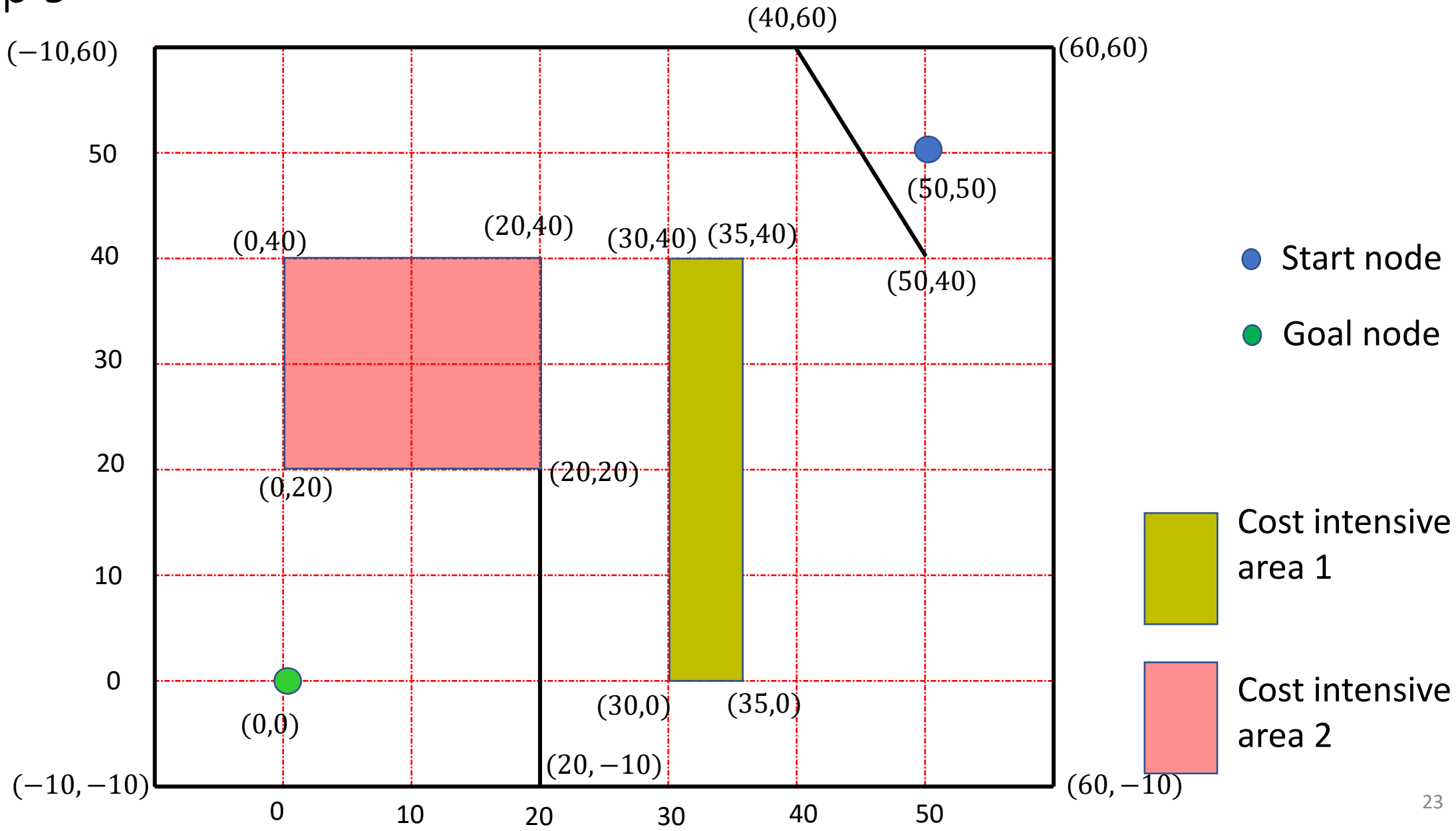
Start node
Goal node
Cost intensive area 1
Cost intensive area 2

Group 9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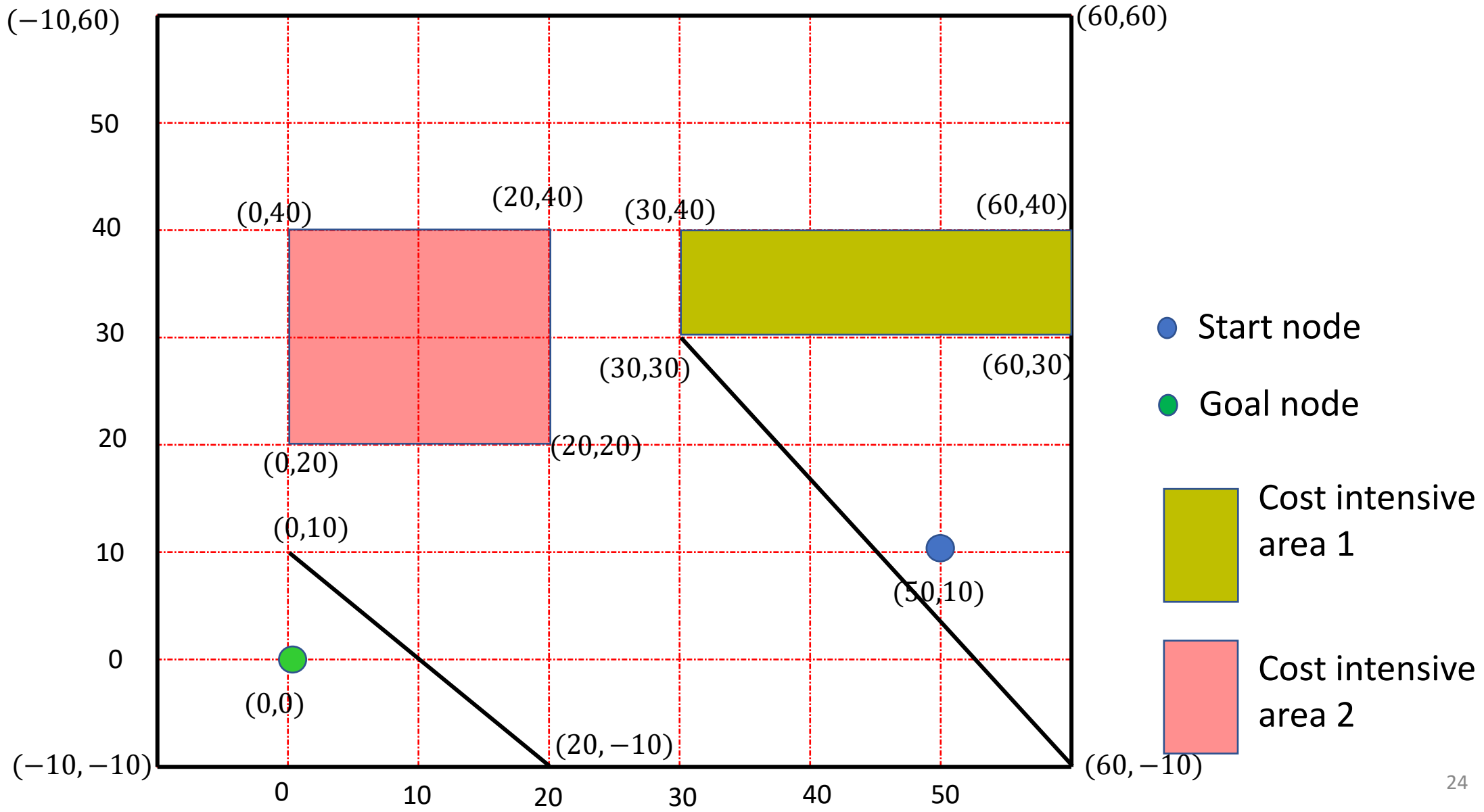
Goal node
Cost intensive area 1
Cost intensive area 2

Group 10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(20,−10)
(60,−10)
Start node
Goal node
Cost intensive area 1
Cost intensive area 2

Task 1 Scenarios

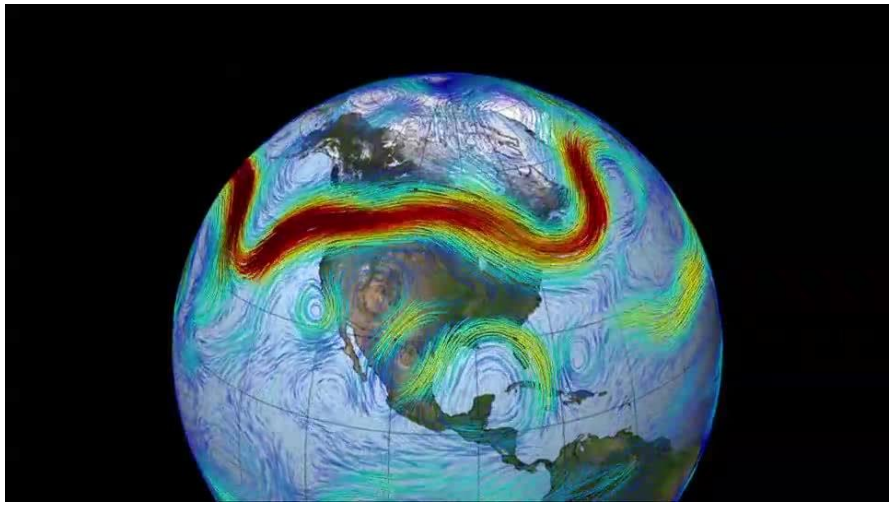
1. Scenario 1
    1. 3000 Passengers need to travel this week from the start to the destination
    2. 12 flights maximum for one week
    3. Time cost = medium and Fuel cost = 0.76 $/kg
2. Scenario 2
    1. 1250 Passengers need to travel within this month from the start to the destination
    2. 5 flights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

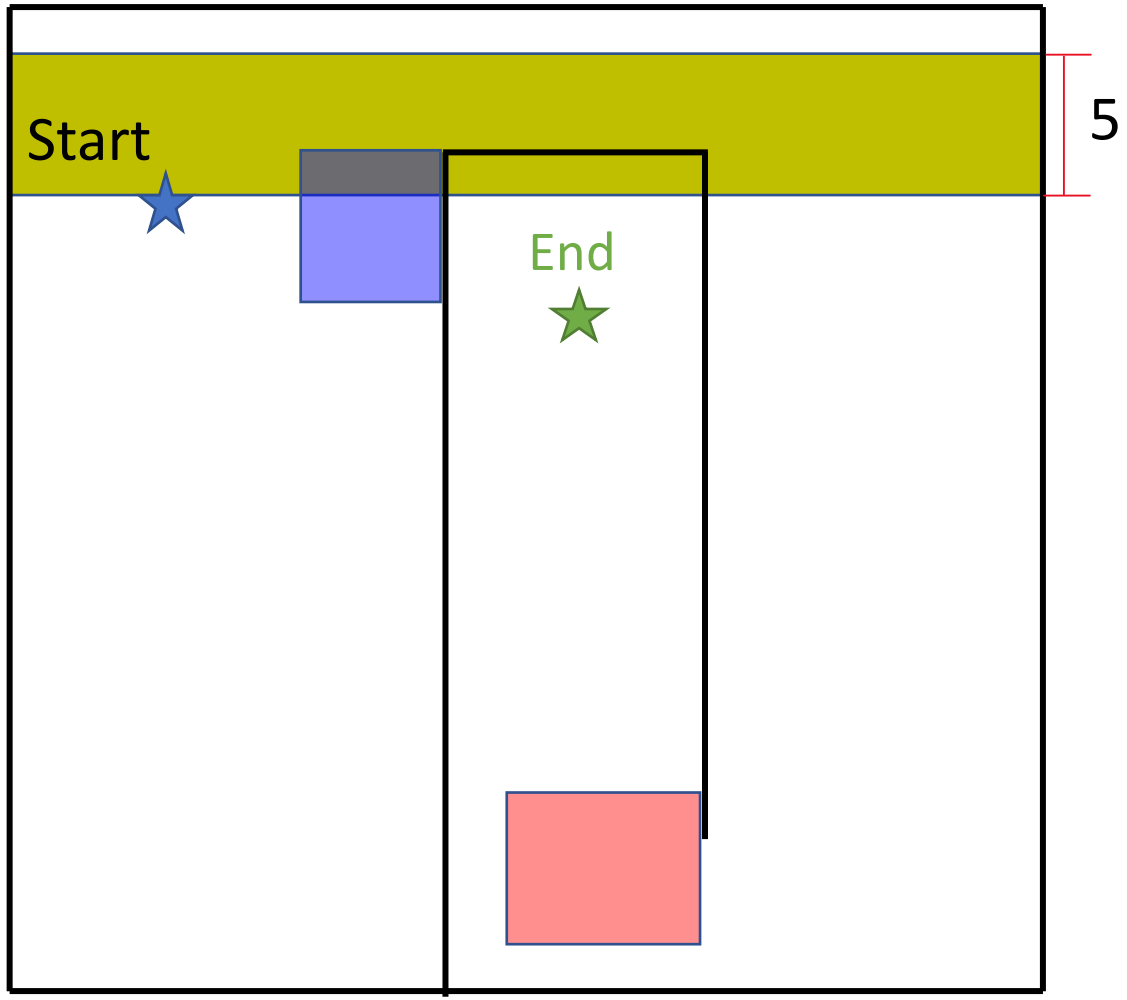
Task 2

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!

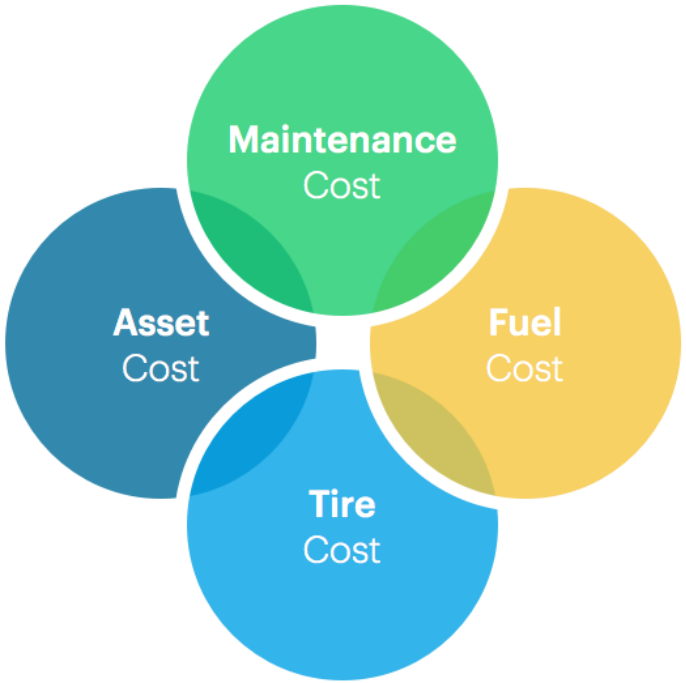
Design a new Aircraft Model that achieve minimum cost for the challenge assigned to your group

(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)

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

- C_F=cost of fuel per kg
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- 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%

Project Additional Tasks (Optional)

Additional Tasks

- Start working on the following Tasks after you finish the previous ones (Create separate .py files so these tasks don't affect each other)
- Additional Tasks:
  - Adding Checkpoints
  - Changing Environment
  - Compare Different Algorithms

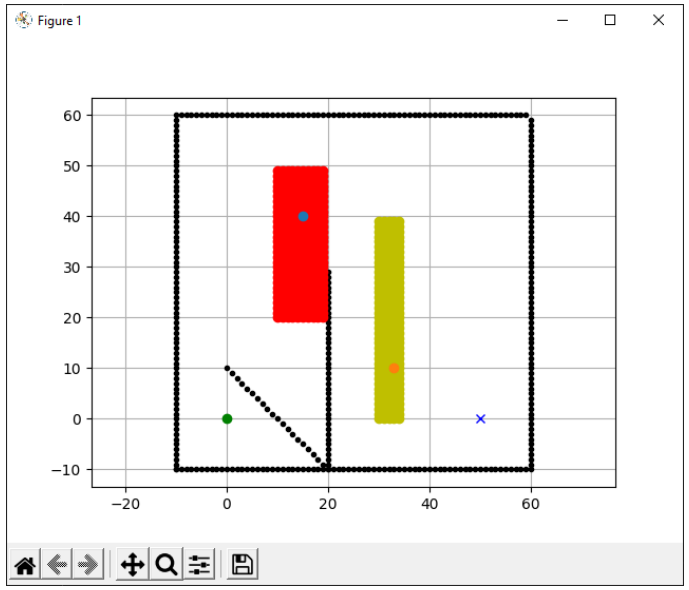
Adding a Checkpoint (Waypoint)

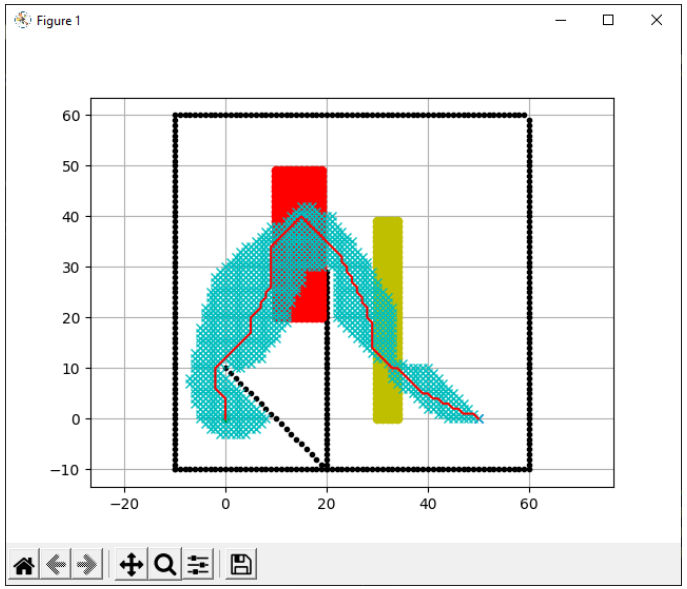
- Assume the Aircraft is a supply craft that must reach 2 drop-off points to drop supplies before heading back to base

1. Add 2 checkpoints:
    - One per each heavy consumption area
2. Reach all checkpoints before arriving at the destination

Adding a Checkpoint

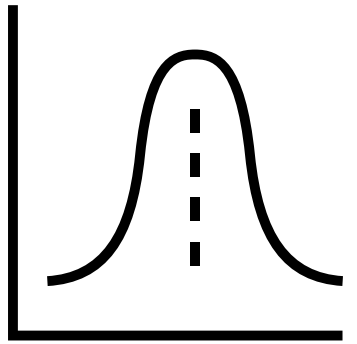
- Requirements:
  1. This is an add-on for the code you are currently working on
  2. Checkpoints should be generated inside the heavy consumption areas
  3. Print the checkpoints, planning and the final path correctly **with different appearance**





Changing Environment

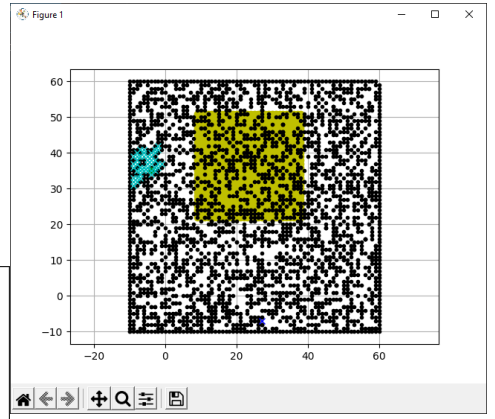
- ***Continue this task using the previous task's code**
- We have been working on the same set of obstacles
- However, Path Planning should be able to work with different obstacle sets
- A **new scenario** per execution

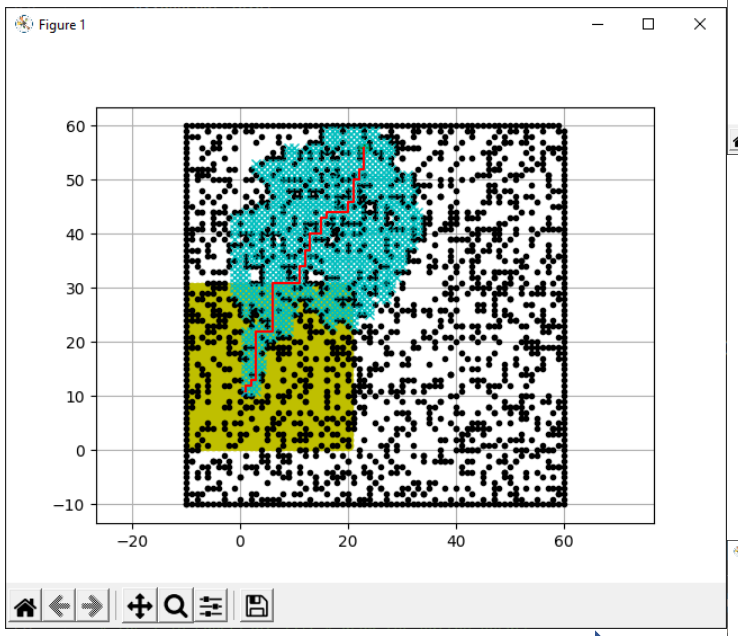


Changing Environment

- Modify the code so that:
  1. Only the fuel-consuming area remains and generate it randomly **with a fixed area (30x30)**
  2. Diagonal movement is **disabled**, change parameter(s) so that the object could travel **within one grid size**
  3. Obstacles are generated randomly with **reasonable density**
  4. Destination and starting points are generated randomly with **at least a 50-unit distance in-between**
  5. Diagonal movements are **disabled**
  6. Plotting of the fuel-consuming area would not cover the obstacles, and obstacles **should not generate** at/near the start and end point

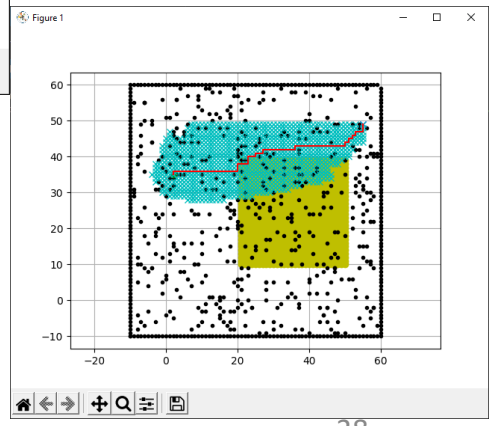
Density too high





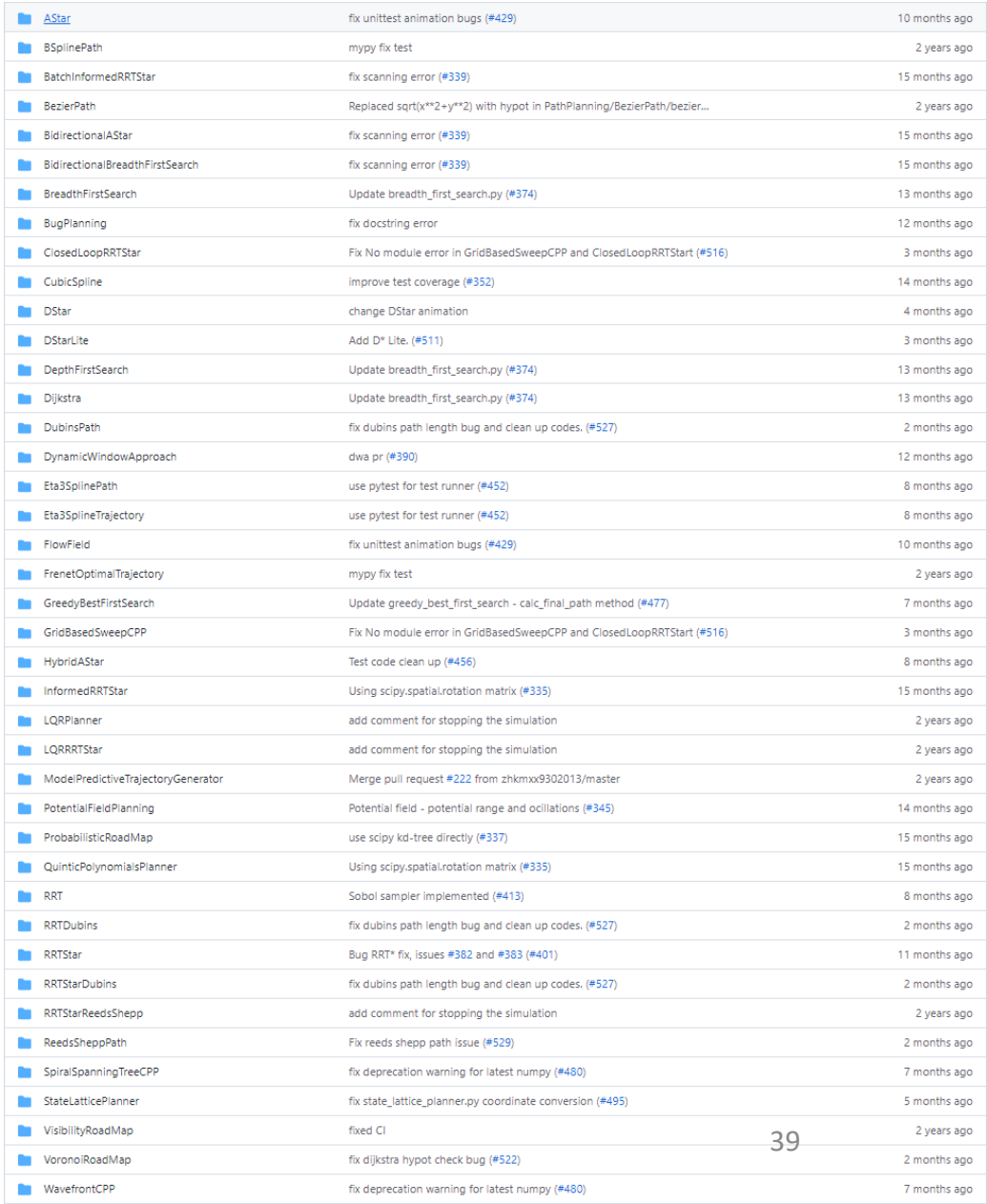
Reasonable

Density too low



Comparing Algorithms

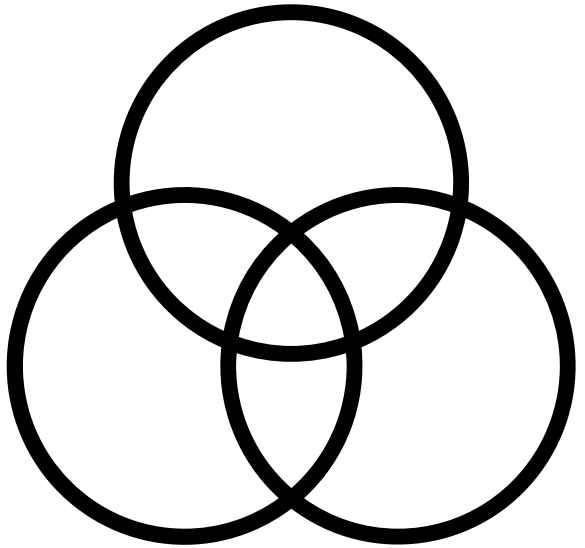
- AStar is only one of the many Pathplanning Algorithms
- Different Algorithms
  - Different theories
  - Different performance
  - Difference limitations and strengths



AStar	fix unittest animation bugs (#429)	10 months ago
BSplinePath	mypy fix test	2 years ago
BatchInformedRRTStar	fix scanning error (#339)	15 months ago
BezierPath	Replaced sqrt(x**2+y**2) with hypot in PathPlanning/BezierPath/bezier...	2 years ago
BidirectionalAStar	fix scanning error (#339)	15 months ago
BidirectionalBreadthFirstSearch	fix scanning error (#339)	15 months ago
BreadthFirstSearch	Update breadth_first_search.py (#374)	13 months ago
BugPlanning	fix docstring error	12 months ago
ClosedLoopRRTStar	Fix No module error in GridBasedSweepCPP and ClosedLoopRRTStart (#516)	3 months ago
CubicSpline	improve test coverage (#352)	14 months ago
DStar	change DStar animation	4 months ago
DStarLite	Add D* Lite. (#511)	3 months ago
DepthFirstSearch	Update breadth_first_search.py (#374)	13 months ago
Dijkstra	Update breadth_first_search.py (#374)	13 months ago
DubinsPath	fix dubins path length bug and clean up codes. (#527)	2 months ago
DynamicWindowApproach	dwa pr (#390)	12 months ago
Eta3SplinePath	use pytest for test runner (#452)	8 months ago
Eta3SplineTrajectory	use pytest for test runner (#452)	8 months ago
FlowField	fix unittest animation bugs (#429)	10 months ago
FrenetOptimalTrajectory	mypy fix test	2 years ago
GreedyBestFirstSearch	Update greedy_best_first_search - calc_final_path method (#477)	7 months ago
GridBasedSweepCPP	Fix No module error in GridBasedSweepCPP and ClosedLoopRRTStart (#516)	3 months ago
HybridAStar	Test code clean up (#456)	8 months ago
InformedRRTStar	Using scipy.spatial.rotation matrix (#335)	15 months ago
LQRPlanner	add comment for stopping the simulation	2 years ago
LQRRRTStar	add comment for stopping the simulation	2 years ago
ModelPredictiveTrajectoryGenerator	Merge pull request #222 from zhkmxx9302013/master	2 years ago
PotentialFieldPlanning	Potential field - potential range and ocillations (#345)	14 months ago
ProbabilisticRoadMap	use scipy kd-tree directly (#337)	15 months ago
QuinticPolynomialsPlanner	Using scipy.spatial.rotation matrix (#335)	15 months ago
RRT	Sobol sampler implemented (#413)	8 months ago
RRTDubins	fix dubins path length bug and clean up codes. (#527)	2 months ago
RRTStar	Bug RRT* fix, issues #382 and #383 (#401)	11 months ago
RRTStarDubins	fix dubins path length bug and clean up codes. (#527)	2 months ago
RRTStarReedsShepp	add comment for stopping the simulation	2 years ago
ReedsSheppPath	Fix reeds shepp path issue (#529)	2 months ago
SpiralSpanningTreeCPP	fix deprecation warning for latest numpy (#480)	7 months ago
StateLatticePlanner	fix state_lattice_planner.py coordinate conversion (#495)	5 months ago
VisibilityRoadMap	fixed CI	2 years ago
VoronoiRoadMap	fix dijkstra hypot check bug (#522)	2 months ago
WavefrontCPP	fix deprecation warning for latest numpy (#480)	7 months ago

Comparing Algorithms

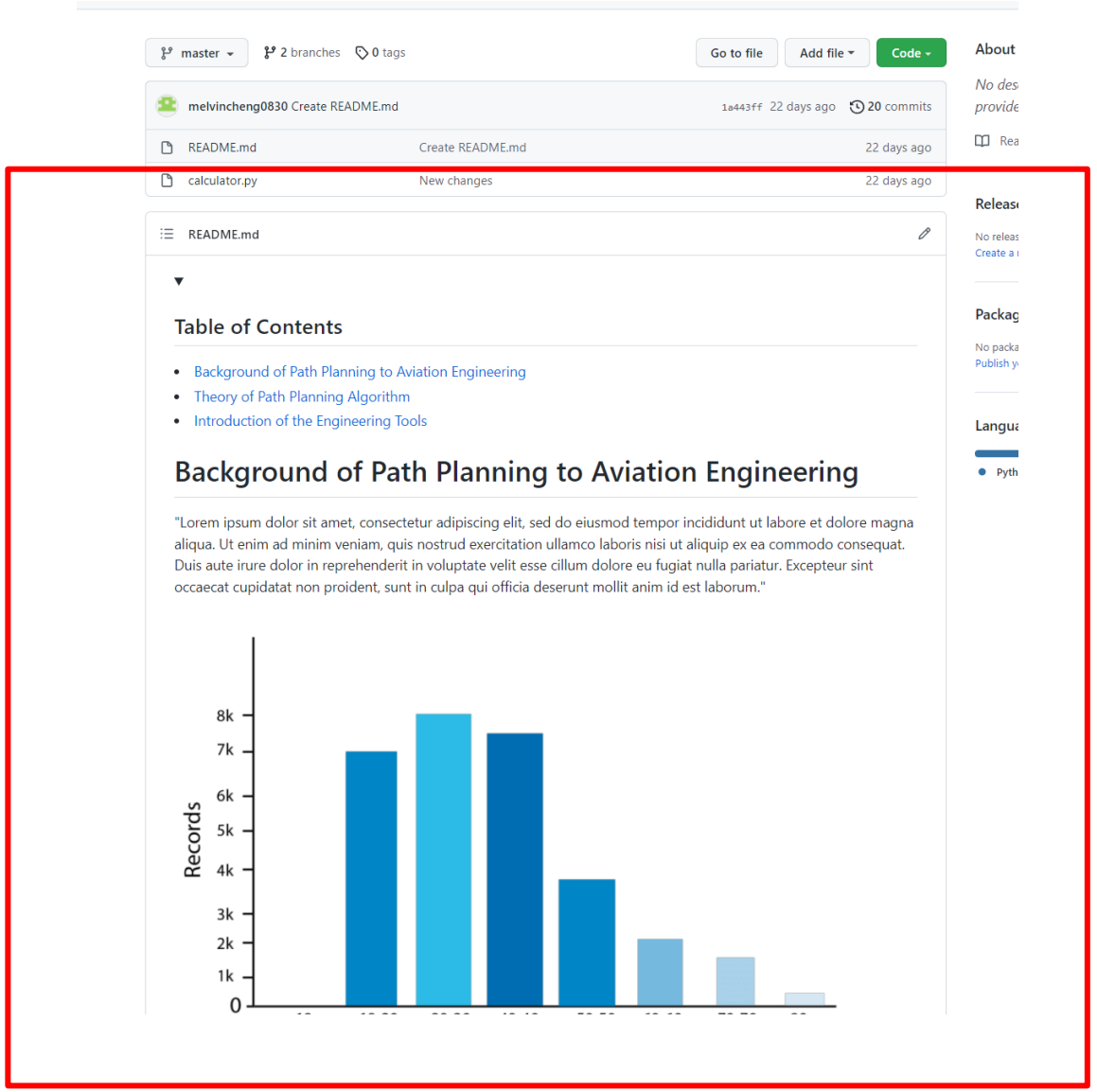
1. Choose 2 more algorithms from the AStar GitHub repository
2. Modify the code so all 3 algorithms are working with the **same obstacle set**
3. Try and compare the algorithms and produce a conclusion



Readme in GitHub Repository

What is a README.md?

- A file for your repository front page
- Contains:
  - Information about your repository
  - Directory
  - Contribution
  - And more...

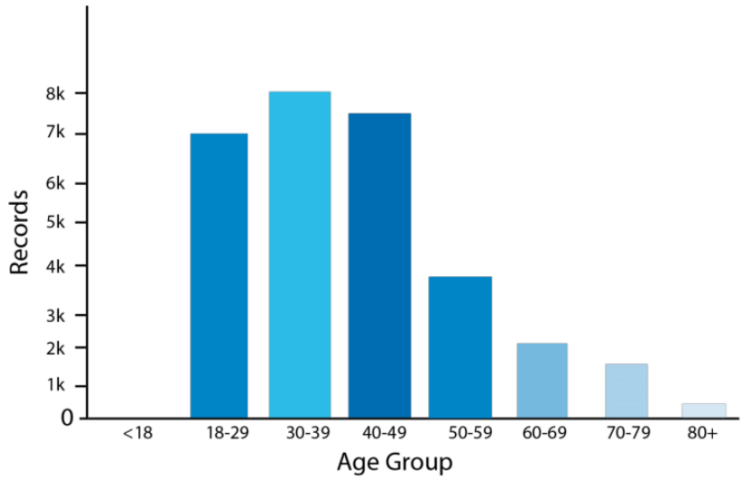


Preview vs Source code of the README.md file

Table of Contents

Background of Path Planning to Aviation Engineering

"Lorem ipsum dolor sit amet, consectetur adipiscing elit, sed do eiusmod tempor incididunt ut labore et dolore magna aliqua. Ut enim ad minim veniam, quis nostrud exercitation ullamco laboris nisi ut aliquip ex ea commodo consequat. Duis aute irure dolor in reprehenderit in voluptate velit esse cillum dolore eu fugiat nulla pariatur. Excepteur sint occaecat cupidatat non proident, sunt in culpa qui officia deserunt mollit anim id est laborum."



"At vero eos et accusamus et iusto odio dignissimos ducimus qui blanditiis praesentium voluptatum deleniti atque corrupti quos dolores et quas molestias excepturi sint occaecati cupiditate non provident, similique sunt in culpa qui officia deserunt mollitia animi, id est laborum et dolorum fuga. Et harum quidem rerum facilis est et expedita distinctio. Nam libero tempore, cum soluta nobis est eligendi optio cumque nihil impedit quo minus id quod maxime placeat facere possimus, omnis voluptas assumenda est, omnis dolor repellendus. Temporibus autem quibusdam et aut officiis debitis aut rerum necessitatibus saepe eveniet ut et voluptates repudiandae sint et molestiae non recusandae. Itaque earum rerum hic tenetur a sapiente delectus, ut aut reiciendis voluptatibus maiores alias consequatur aut perferendis doloribus asperiores repellat."

Preview

```
<!-- TABLE OF CONTENTS -->
<details open="open">
  <summary><h2 style="display: inline-block">Table of Contents</h2></summary>
    <li><a href="#Background-of-Path-Planning-to-Aviation-Engineering">Background of Path Planning to Aviation Engineering</a></li>
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  </ol>
</details>



<!-- ABOUT THE PROJECT -->
# Background of Path Planning to Aviation Engineering

"Lorem ipsum dolor sit amet, consectetur adipiscing elit, sed do eiusmod tempor incididunt ut labore et dolore magna aliqua. Ut enim ad minim veniam, quis nostrud exercitation ullamco laboris nisi ut aliquip ex ea commodo consequat. Duis aute irure dolor in reprehenderit in voluptate velit esse cillum dolore eu fugiat nulla pariatur. Excepteur sint occaecat cupidatat non proident, sunt in culpa qui officia deserunt mollit anim id est laborum."

![This is an image](https://www.researchgate.net/profile/Jan-Bieser/publication/333867743/figure/fig2/AS:771428257374208@1560934237674/Bar-chart-showing-the-number-of-observations-value-attribute-for-each-age-group-key.png)

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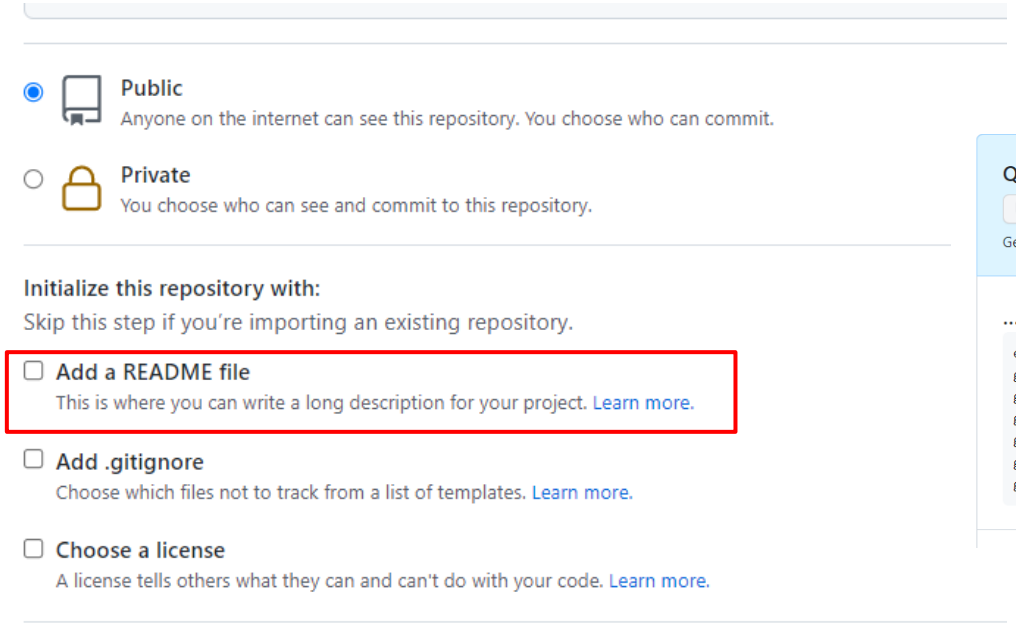
"On the other hand, we denounce with righteous indignation and dislike men who are so beguiled and demoralized by the charms of pleasure of the moment, so blinded by desire, that they cannot foresee the pain and trouble that are bound to ensue; and equal blame belongs to those who fail in their duty through weakness of will, which is the same as saying through shrinking from toil and pain. These cases are perfectly simple and easy to distinguish. In a free hour, when our power of choice is untrammelled and when nothing prevents our being able to do what we like best, every pleasure is to be welcomed and every pain avoided. But in certain circumstances and owing to the claims of duty or the obligations of business it will frequently occur that pleasures have to be repudiated and annoyances accepted. The wise man therefore always holds in these matters to this principle of selection: he rejects pleasures to secure other greater pleasures, or else he endures pains to avoid worse pains."

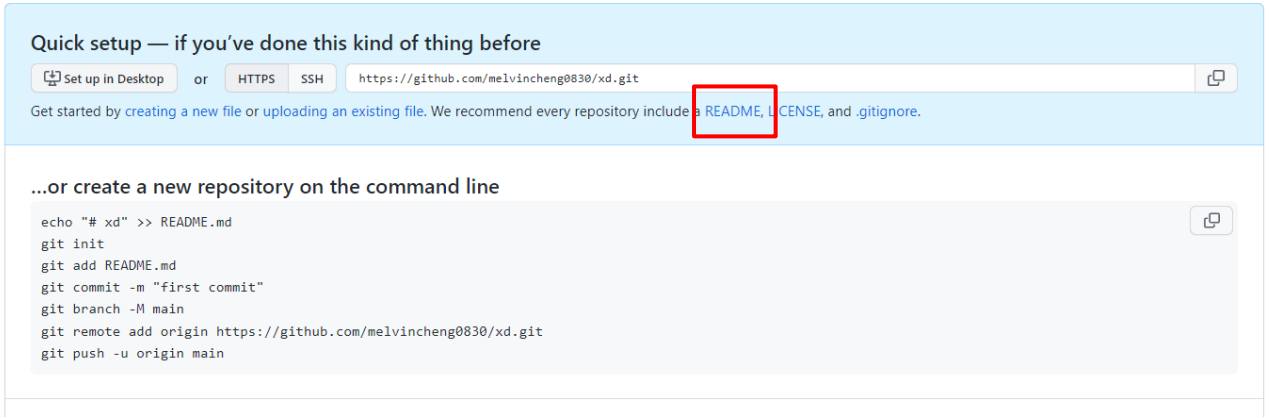
```

Source Code

How to create a README.md

- You can create a README before or after your create your repository





Basic Features

1. Basic text, titles and subtitles
2. Table of contents
3. Inserting figures / photos

Basic text, titles and subtitles

- To create normal texts, simply type them in to the source code
- To create a main title, add a '#' at the beginning
  - *# This is the Main Title*
  - *##### More # makes smaller titles*

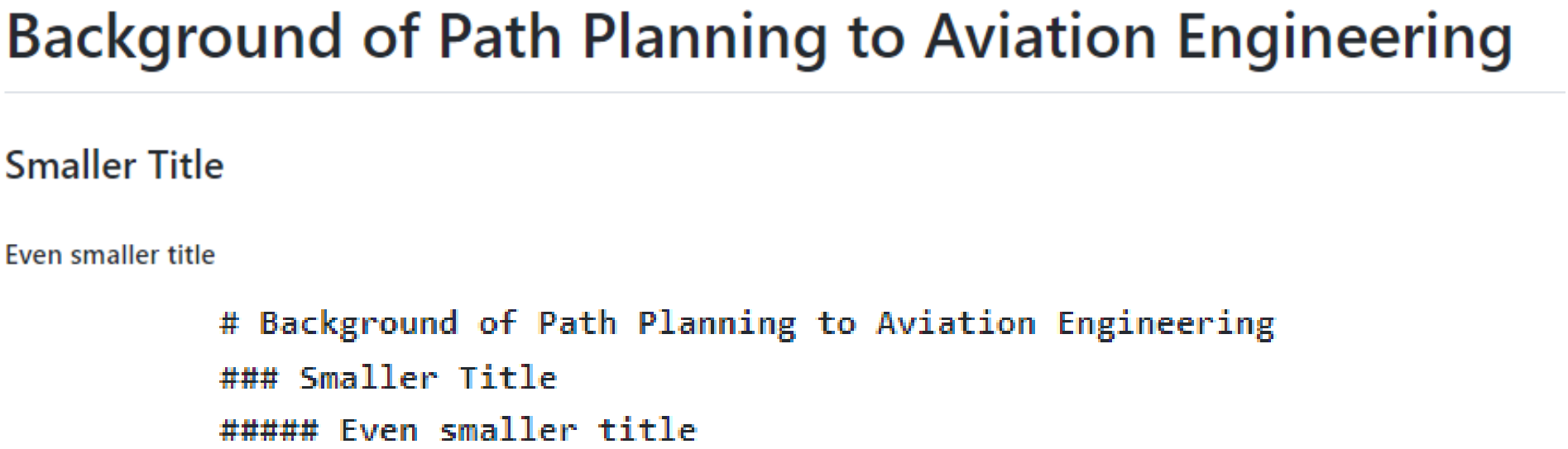


Table of Contents

- You need to have titles before creating a table of Contents
- Format of a table of contents
- Everything like fonts, text sizes and more can be altered!

```
<!-- TABLE OF CONTENTS -->
<details open="open">
  <summary><h2 style="display: inline-block">Table of Contents</h2></summary>
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</details>
```

Text to be shown

Titles to be directed to

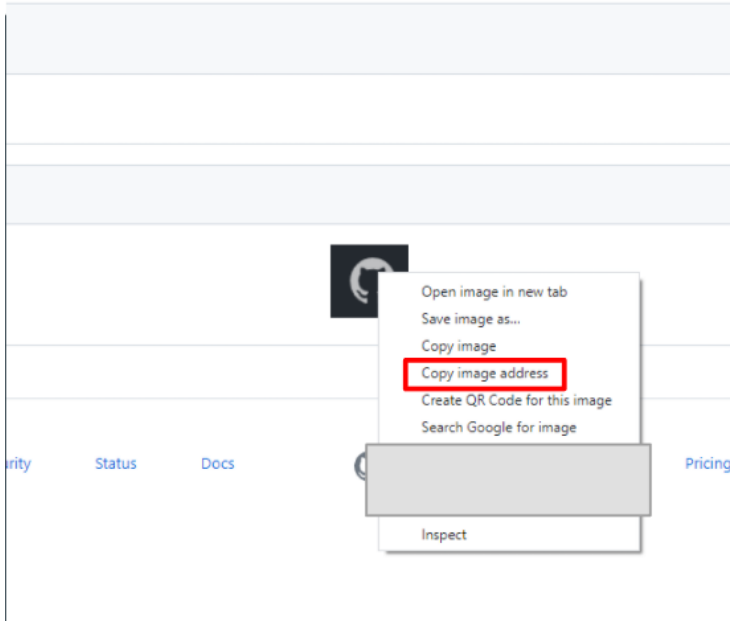
Inserting Figures / photos

- You need to provide a link of the photo for this to work
- For screenshots you make, you can upload them to your repository and do the same thing by copying the image address!
- Example:

```
![This is an image](https://www.researchgate.net/profile/Jan-Bieser/publication/333867743/figure/fig2/AS:771428257374208@1560934237674/Bar-chart-showing-the-number-of-observations-value-attribute-for-each-age-group-key.png)
```

Message shown when picture cannot load

You can get the link for a photo by right clicking on it and select 'Copy link address'



Full Example

Table of Contents

Background of Path Planning to Aviation Engineering

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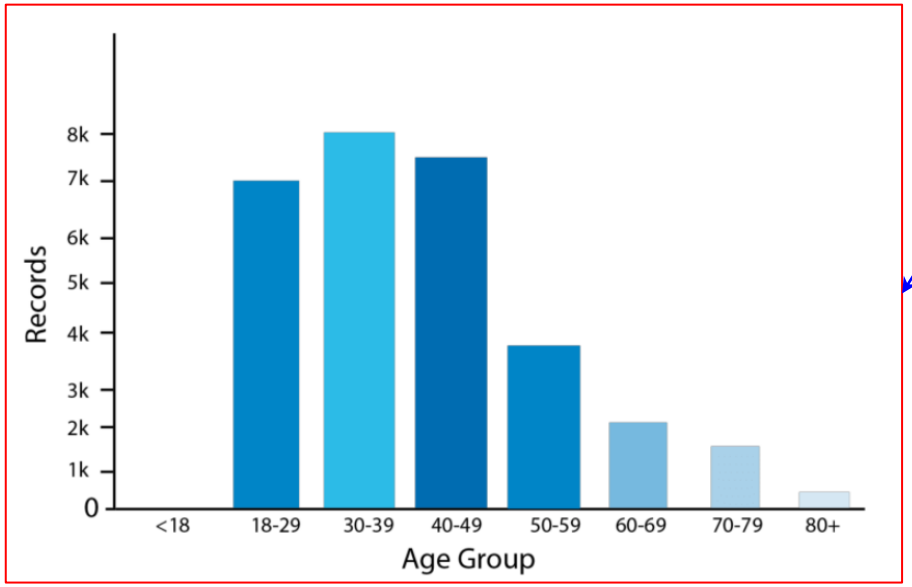

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```

- Just like writing an HTML page
- Different formatting syntax creates corresponding visual formatting for the README page

Your README.md Report

- You are required to include the basic features mentioned in this PPT
  - Table of content, image, titling
- For bonus marks:
  - Search for more features on the web and include them appropriately to your README file!
  - What to add?
    - A gif showing your path planning plot
    - Other potential materials you find useful
- Useful links:
  - GitHub official tutorial