Anbang Yang — ay1620

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Intro to Swarm Robotics + Graph Theory (Lectures 1 and 2)

Submit all code, drawings, video, and typed answers via Brightspace. All written responses must be typed.

1. Discuss the following concepts:
   a. Explain the difference between centralized and decentralized control.
      - **Centralized control:** one component is identified as the controller and is responsible for coordinating the execution of other components.
      - **Decentralized control:** a control system in which the logic functions and input/output functions are located on separate equipment or subsystems and operate independently of one another.

   b. Explain the difference between synchronous and asynchronous communication.
      - **Synchronous communication:** massage can only be exchanged in real time. It necessitates that the transmitter and receiver be in the same location and/or time.
      - **Asynchronous communication:** when information may be exchanged regardless of time. It does not demand the recipient's immediate attention, permitting them to answer at their convenience.

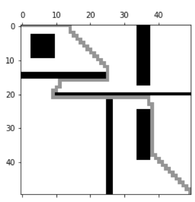
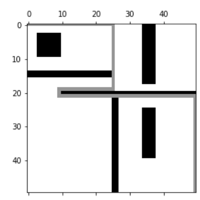
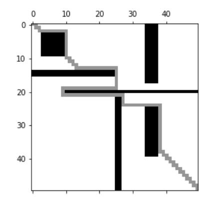
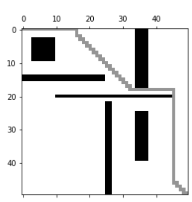
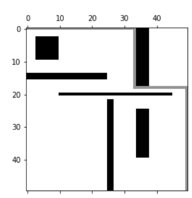
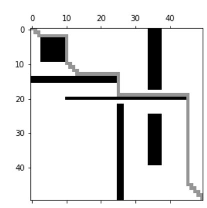
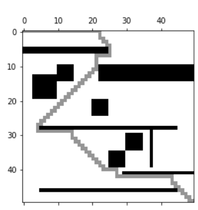
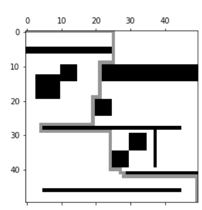
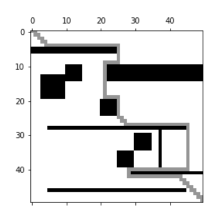
   c. Explain a scenario where a heterogeneous swarm might be more advantageous than a homogeneous swarm.

      In search-and-rescue missions, a heterogeneous swarm may be preferable to a homogeneous one. In such circumstances, the swarm may need to investigate a huge and complicated environment, such as a disaster site, in order to locate and rescue people. The efficiency and efficacy of the search and rescue effort can be enhanced by the use of heterogeneous swarms composed of agents with varying sensory capabilities, mobility capacities, and communication skills.

      For example, a swarm of drones, ground robots, and human operators can collaborate to cover a larger area, share information and resources, and adapt to the changing environmental circumstances. Ground robots can maneuver through trash and small passageways, and human operators can make strategic judgments based on the data provided by the agents.

2. <u>Implement an A* algorithm for one robot in an obstacle filled environment. Come up with two different heuristics to implement and write out the logic behind your choice. Animate both paths. Compare the two heuristics and explain which is more optimal in terms of memory.</u>

   Three heuristics and their trajectory on three mazes created:

No heuristics	Manhattan Distance	Euclidean Distance
h(i,j)=0	h(i,j)=|i-goali|+|j-goalj|	h(i,j)=sqrt((i-goali)^2+(j-goalj)^2)
		
Path Length: 130.0 Tested nodes: 2171	Path Length: 130.0 Tested nodes: 838	Path Length: 130.0 Tested nodes: 1985
		
Path Length: 98.0 Tested nodes: 2008	Path Length: 98.0 Tested nodes: 98	Path Length: 98.0 Tested nodes: 737
		
Path Length: 140.0 Tested nodes: 2047	Path Length: 140.0 Tested nodes: 1315	Path Length: 140.0 Tested nodes: 1973

The code can be found at author's github repo. The logic to choose these three heuristics are:

- No heuristics: no information from current location to the destination
- Manhattan Distance: guess the distance to the destination from current location is the sum of differences on x axis and y axis
- Euclidean Distance: guess the distance to the destination from current location is the straight line between them

As shown in previous calculation via our script, the Manhattan Distance outperformed other two heuristics in terms of the tested nodes which is more optimal in terms of memory.

3. Now expand your program to include at least 3 robots using the superior heuristic. Animate the path. What additional constraints did you have to consider to make the heuristic work for the multi-robot system?

Maze 1

Num robots: 5

Maze 2

Num robots: 7

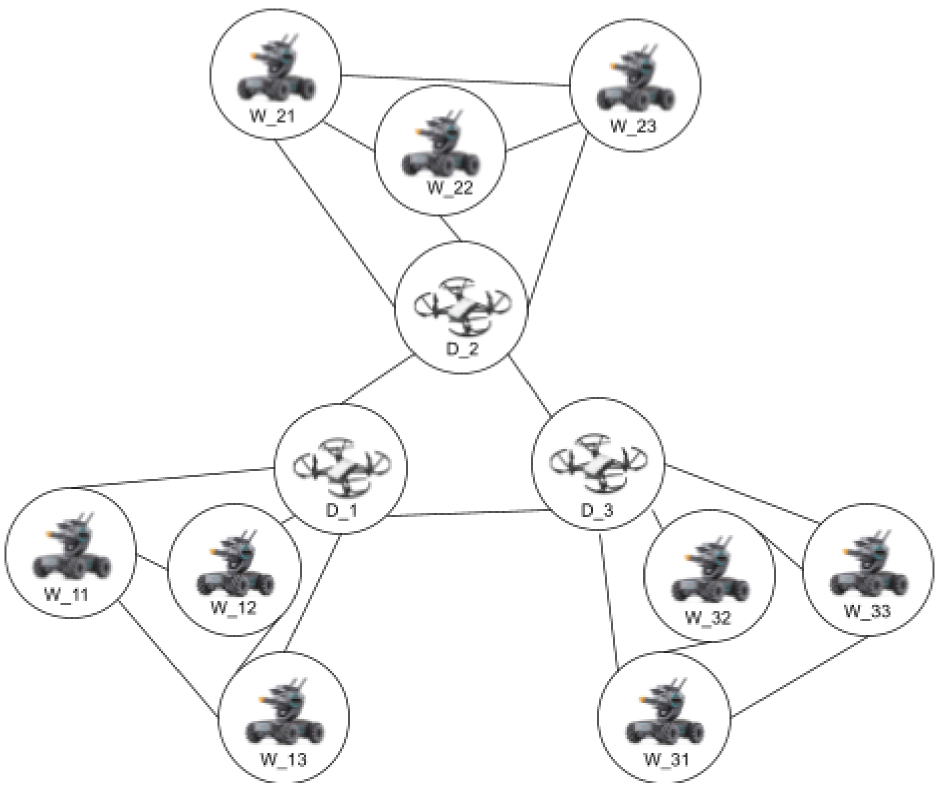
Maze 3

Num robots: 5

I randomly assign n robots into each maze, and the destinations are set to the bottom right coner. Code can be found in my github repo.

In this algorithm, we need to consider the constraints imposed by other robots when computing the path of each robot.

4. We want to deploy a team of robots for a recognition and rescue mission. We have three drones and nine wheeled robots. We create three teams, containing each three wheeled robots and one drone. Due to the terrain conditions, the wheeled robots can only communicate with the same members of the team and do not have access to the other robots. The drones can communicate with the other drones but not with the mobile robots of other teams.
    a. Draw the communication graph associated to this scenario (label the vertices with the robot type).



    b. Write down the graph in terms of a set of edges and vertices.

$V = \{D_1, D_2, D_3, W_{11}, W_{12}, W_{13}, W_{21}, W_{22}, W_{23}, W_{31}, W_{32}, W_{33}\}$

$W = \{(D_1, D_2), (D_2, D_3), (D_3, D_1),(D_1, W_{11}), (D_1, W_{12}), (D_1, W_{13}),$
$(D_2, W_{21}), (D_2, W_{22}), (D_2, W_{23}), (D_3, W_{31}), (D_3, W_{32}), (D_3, W_{33}),$
$(W_{11}, W_{12}), (W_{12}, W_{13}), (W_{13}, W_{11}), (W_{21}, W_{22}), (W_{22}, W_{23}), (W_{23}, W_{21}),$
$(W_{31}, W_{32}), (W_{32}, W_{33}), (W_{33}, W_{31})\}$

c. Is there a path from a mobile robot of the first team to a mobile robot of the second and third team? Explain why.

Yes, there is paths from a mobile robot of the first team to a mobile robot of the second or third team. Although that wheeled robots can only interact with other members of their team and not with other teams, and drones can only connect with other drones but not with mobile robots from other teams, the robot of the first team has a path from the drone in the first team to the drone in the first or third team and to the wheeled robots in their team, for example:

$$W_{11} \rightarrow D_1 \rightarrow D_2 \rightarrow W_{23}$$

d. Compute the adjacency, degree and incidence matrices of the graph.

Adjacency matrix A:

[[0, 1, 1, 1, 1, 1, 0, 0, 0, 0, 0, 0],
[1, 0, 1, 0, 0, 0, 1, 1, 1, 0, 0, 0],
[1, 1, 0, 0, 0, 0, 0, 0, 0, 1, 1, 1],
[1, 0, 0, 0, 1, 1, 0, 0, 0, 0, 0, 0],
[1, 0, 0, 1, 0, 1, 0, 0, 0, 0, 0, 0],
[1, 0, 0, 1, 1, 0, 0, 0, 0, 0, 0, 0],
[0, 1, 0, 0, 0, 0, 0, 1, 1, 0, 0, 0],
[0, 1, 0, 0, 0, 0, 1, 0, 1, 0, 0, 0],
[0, 1, 0, 0, 0, 0, 1, 1, 0, 0, 0, 0],
[0, 0, 1, 0, 0, 0, 0, 0, 0, 0, 1, 1],
[0, 0, 1, 0, 0, 0, 0, 0, 0, 1, 0, 1],
[0, 0, 1, 0, 0, 0, 0, 0, 0, 1, 1, 0]]

Degree matrix D:

[[5, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0],
[0, 5, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0],
[0, 0, 5, 0, 0, 0, 0, 0, 0, 0, 0, 0],
[0, 0, 0, 3, 0, 0, 0, 0, 0, 0, 0, 0],
[0, 0, 0, 0, 3, 0, 0, 0, 0, 0, 0, 0],
[0, 0, 0, 0, 0, 3, 0, 0, 0, 0, 0, 0],

[0, 0, 0, 0, 0, 0, 3, 0, 0, 0, 0, 0],
[0, 0, 0, 0, 0, 0, 0, 3, 0, 0, 0, 0],
[0, 0, 0, 0, 0, 0, 0, 0, 3, 0, 0, 0],
[0, 0, 0, 0, 0, 0, 0, 0, 0, 3, 0, 0],
[0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 3, 0],
[0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 3]]

Here is the incidence matrix B of the graph:

[[1, 0, 1, 1, 1, 1, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0],
[1, 1, 0, 0, 0, 0, 1, 1, 1, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0],
[0, 1, 1, 0, 0, 0, 0, 0, 0, 1, 1, 1, 0, 0, 0, 0, 0, 0, 0, 0],
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[0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 1, 0, 0, 0, 0, 0, 0, 1, 1]]