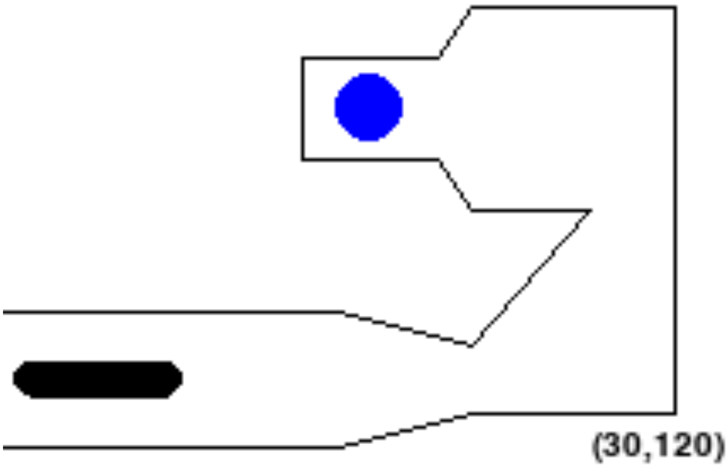


CS440/ECE448 Fall 2023

Assignment 5: Configuration Space Planning (Geometry)

Due date: Monday, October 9 11:59pm

In this assignment you will write code that transforms a shapeshifting alien path planning problem into a graph search problem. See the Robotics sections of the lectures for background information.

General guidelines

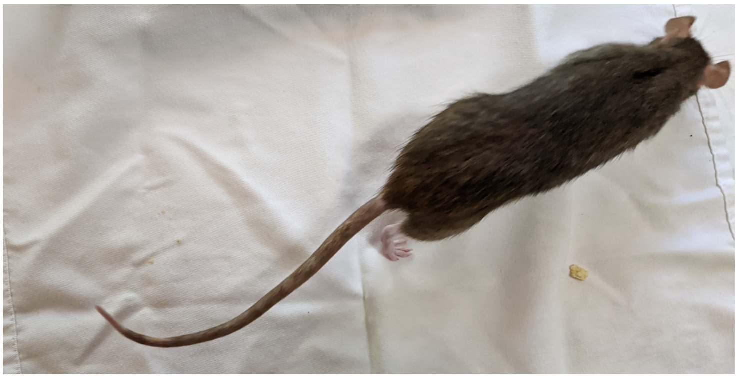
Basic instructions are the same as in MP 1. Specifically, you should be using Python 3.8 with pygame installed, and you will be submitting the code to Gradescope. Your code may import modules that are part of the standard python library, and also numpy and pygame.

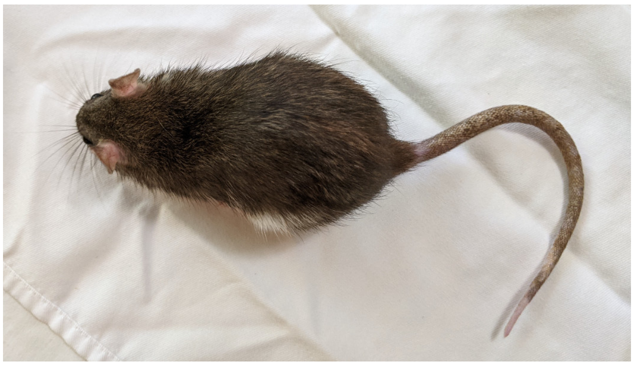
For general instructions, see the main MP page and the syllabus.

You will need to adapt your A* code from MP 3/4.

Problem Statement

Many animals can change their aspect ratio by extending or bunching up. This allows animals like cats and rats to fit into small places and squeeze through small holes.

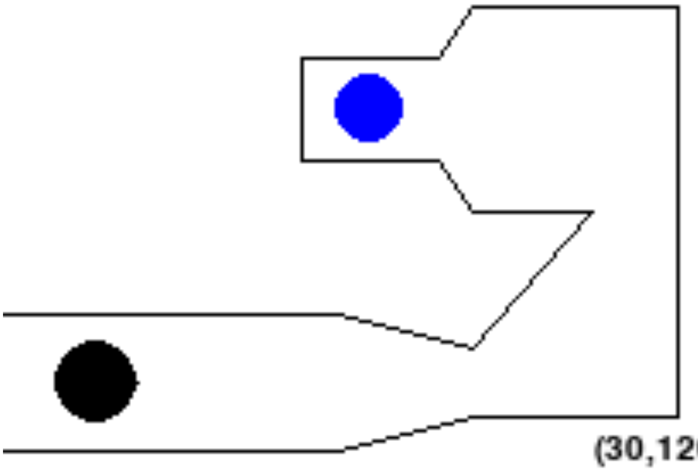




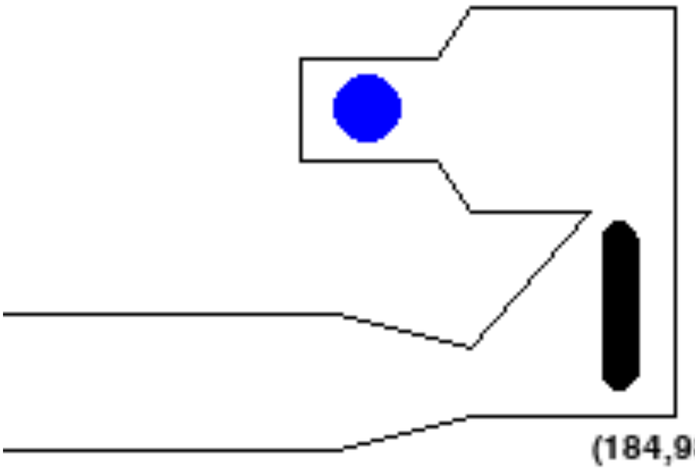
You will be moving an alien robot using straight-line paths between waypoints, based on this idea, to reach a goal. Specifically, the robot lives in 2D and has three degrees of freedom:

- It can move the (x,y) position of its center of mass.
- It can switch between three forms: a long horizontal form, a round form, and a long vertical form.

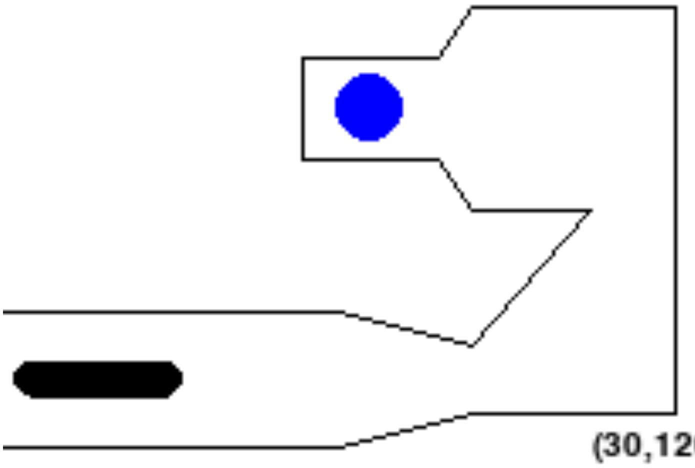
Notice that the robot cannot rotate. Also, to change from the long vertical form to/from the long horizontal form, the robot must go through the round form, *i.e*., it cannot go from its vertical oblong shape to its horizontal oblong shape directly.



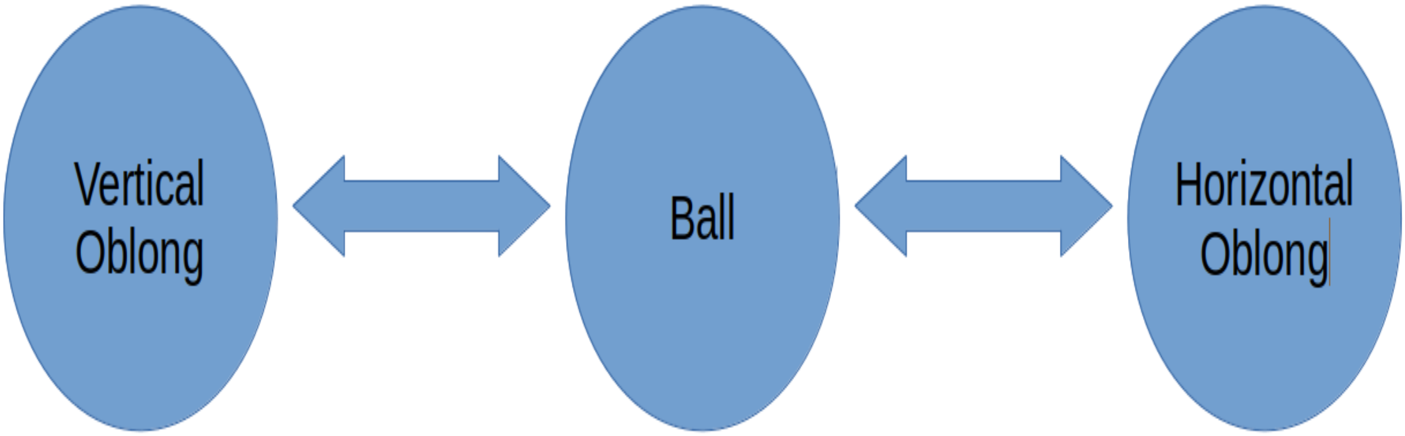
(30,120)



(184,98)



(30,120)

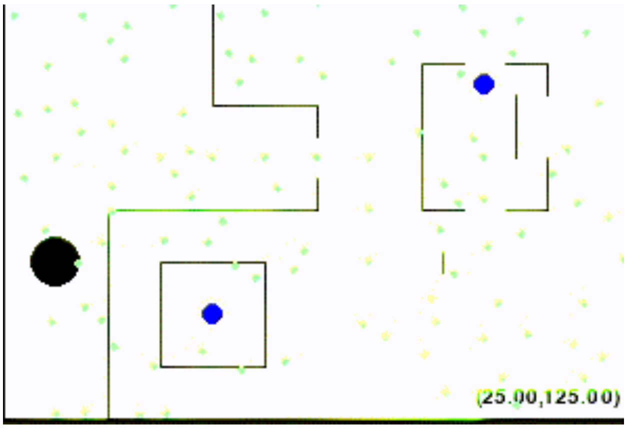


The round form is a disk (or a filled circle). The horizontal or vertical long form is a "sausage" shape, defined by a line segment and a distance "d", *i.e.*, **any point within a given distance "d" of the LINE SEGMENT between the alien's head and tail is considered to be within the alien** .

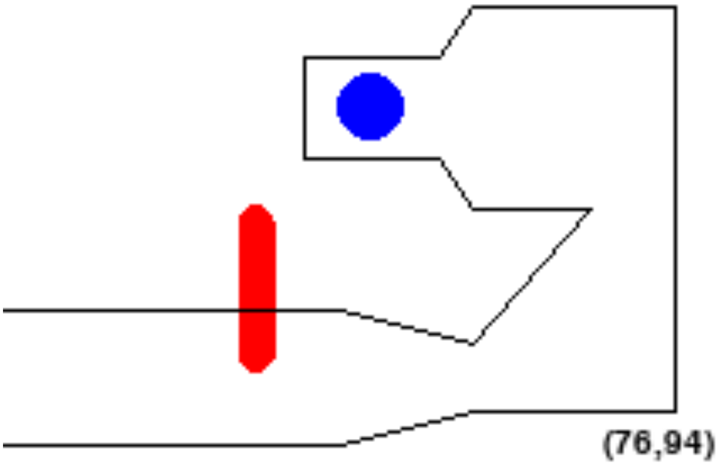
For each planning problem you will be given a 2D environment specified by:

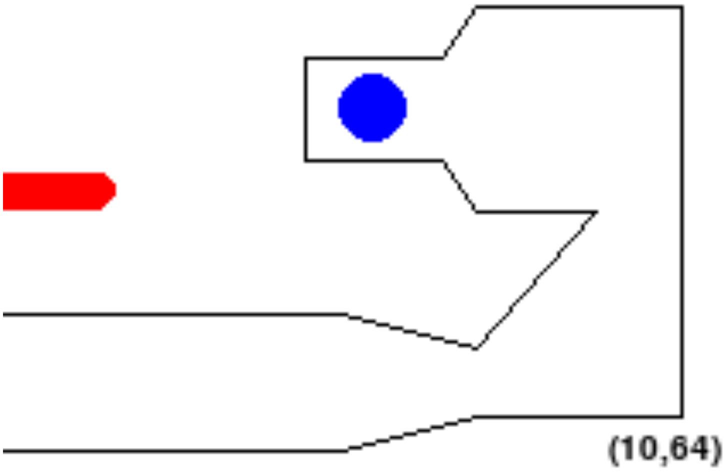
- The size of the workspace.
- The widths of the long and round forms.
- The starting (x,y) center-of-mass position and shape of the alien.
- A list of waypoints, described by an (x, y) position.
- A list of goals, each of which is defined by an (x, y) position.
- A set of obstacles, each of which is a line segment.

You need to find a shortest path for the alien robot from its starting position to **ONE** of the goal positions using straight-line paths between waypoints. An example is shown below:



The tricky bit is that the alien may not pass through any of the obstacles. Also, no part of the robot should go outside the workspace. So configurations like the following are **NOT** allowed:





Also note that, since we choose waypoints randomly, there may be some waypoints that are too close to the edge or obstacles for particular shapes. To account for this, you will need to remove invalid waypoints before executing your search.

We consider the maze solved once the alien's centroid is at a goal position, as long as the alien is not violating any constraint (*i.e.*, not out of bounds or touching a wall).

To solve MP5 and MP6, you will go through three main steps, completing only the geometry for MP5:

- Write geometry functions to check if straight-line paths are valid.
- Finish implementing a new state representation for this problem.
- Adapt your MP3/4 State and A* code to be able to search in three dimensions (x, y, and shape).
    - This is primarily a housekeeping activity to ensure your code is not hardcoded to work for a specific type of search, but can handle generic search spaces.

Search Formulation

In order to adapt A* to this problem, we need to understand how searching in the maze can be formulated as searching through a weighted graph.

First, the nodes of the graph will include the entire state space. In this problem, the state space is a set of tuples (x, y, shape) for all waypoints and goals (x, y) and shapes such that (x, y, shape) is in bounds and doesn't touch an obstacle.

An edge exists between two nodes if there is a valid straight-line path between their states in the maze. Next, we define the cost, or edge weights:

- if the centroid changes, but shape does not, the cost is the manhattan distance between the positions
- if the alien changes shape, then there is a constant cost of 10

The objective, then, is to find the lowest cost path to a goal node. You will implement this search in MP6. However, in this case, to improve runtime, we only consider the K-nearest neighbors in our search.

Part 0: Understanding Map configuration

Each scene (or problem) is defined in a settings file. We wrote the code to read each settings file for you.

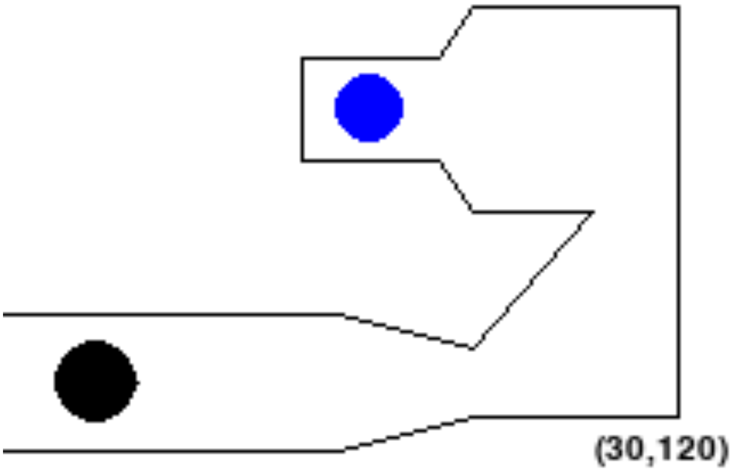
The settings file must specify the alien's inital position, geometry of the alien in its different configurations, the waypoints, the goals and the edges of the workspace. Here is a sample scene configuration:

```
[Test1]
Window : (220, 200)                    # (Width, Height)
Obstacles : [
              (0,90,100,90),  # (startx,starty,endx,endy)
              (100,90,140,105),
              (140,105,175,70),
              (175,70,140,70),
              (140,70,130,55),
              (130,55,90,55),
              (90,55,90,25),
              (90,25,130,25),
              (130,25,140,10),
              (140,10,210,10),
              (210,10,210,140),
              (210,140,140,140),
              (140,140,100,150),
              (100,150,0,150)
          ]
Goals : [
          (110, 40)              # (x-coordinate, y-coordinate)
      ]
WayPoints: [
          (87, 25),
          (198, 183),
          ...
      ]
Lengths: [40,0,40]
Widths: [11,25,11]
StartPoint: [30,120]
```

- Window: The window size for the given example map is 220x200 pixels. **Note that (0, 0) is the top-left corner and (220, 200) is the bottom-right corner** .
- Lengths: The lengths of the robot are in the form ['Horizontal Length', 'Ball length (always 0)', 'Vertical Length']. The length of the robot is defined by the distance between its head and tail
- Widths: widths of the robot represent the radius of the circle that is added to the line segment "body" of the alien, *i.e.*. how far away from the line segment defining the body is still considered to be "inside" the robot. These are ordered in the same manner as the Lengths
- Obstacles: There are many walls in the maze which are represented by a list of endpoints for line segments in the format (startx, starty, endx, endy)
- Goals / Waypoints: A list of waypoints and a list of goals specified in the form (x, y). In this particular

maze, there is one goal at (110,40).
- The alien is set to start at the position (30, 120), in its default disk configuration
- The name of this map is Test1

Here is how the map from this configuration looks without waypoints:



You can play with the maps (stored in config file "maps/test_config.txt") by manually controlling the robot by executing the following command:

python3 mp5_6.py --config maps/test_config.txt --map Test1 --human

Feel free to modify the config files to do more self tests by adding test maps of your own.

Once the window pops up, you can manipulate the alien using the following keys:

- w / a / s / d: move the alien up / left / down/ right
- q / e: switch between horizontal, ball, and vertical forms of the alien. "q" will cycle backwards (Vertical -> Ball -> Horizontal) and "e" will cycle forwards (Horizontal -> Ball -> Vertical

While implementing your geometry.py file, you can also use this mode to manually verify parts of your solution, as the alien should turn red when touching an obstacle or out of bounds, and should turn green when validly completing the course, as shown in the initial figures.

Part 1: Geometry

The first step is to work out the geometrical details to check moves in the configuration space.

The alien robot has two forms that are represented with geometric shapes:

Form 1 (Ball): A disk with a fixed radius. This entire disk is the alien's body.

Form 2 (Oblong): An oblong (sausage shape). This is represented as a line segment with a fixed length and a radius. Any point within the specified radius of the line segment belongs to the alien's body, hence its sausage-like appearance.

We provide a helper class to help you: Alien. **Do not modify this class** . To solve this MP, you will likely find the following Alien methods to be useful:

alien.py

- get_centroid(): Returns the centroid position of the alien (x,y)
- get_head_and_tail(): Returns a list with the (x,y) coordinates of the alien's head and tail [(x_head,y_head),(x_tail,y_tail)], which are coincidental if the alien is in its disk form.
- get_length(): Returns the length of the line segment of the current alien shape
- get_width(): Returns the radius of the current shape. In the ball form this is just simply the radius. In the oblong form, this is half of the width of the oblong, which defines the distance "d" for the sausage shape.
- is_circle(): Returns whether the alien is in circle or oblong form. True if alien is in circle form, False if oblong form.
- set_alien_pos(pos): Sets the alien's centroid position to the specified pos argument
- set_alien_shape(shape): transforms the alien to the passed shape

The main geometry problem is then to check whether

- the alien runs into obstacles on a path between waypoints
- all parts of the alien remain within the given window (bounds)

To do this, you need to implement the following functions:

geometry.py

- is_alien_within_window(alien: Alien, window: Tuple[int]): Determine whether the alien stays within the window.
- does_alien_touch_wall(alien: Alien, walls: List[Tuple[int]]): Determine whether the alien touches a wall
- does_alien_path_touch_wall(alien: Alien, walls: List[Tuple[int]], waypoint: Tuple[int, int]): Determine whether the alien's straight-line path from its current position to the waypoint touches a wall.

These functions are easier to implement if you know how to compute (1) distances between a point and a line segment for these functions, as well as (2) distances between two line segments. You will also want to be able to check if a point lies inside a polygon. So you need to implement four additional helper functions in geometry.py for computing these quantities (we recommend they be implemented in the order below):

- point_segment_distance(point, segment): Compute the Euclidean distance from a point to a line segment, defined as the distance from the point to the closest point on the segment (not a line!).
- do_segments_intersect(segment1, segment2): Determine whether two line segments intersect.
- segment_distance(segment1, segment2): Compute the Euclidean distance between two line segments, defined as the shortest distance between any pair of points on the two segments.
- is_point_in_polygon(point, polygon): Determine whether a point is in a parallelogram.

Lecture note "geometry cheat sheet" should be helpful, as well as drawing down and considering some examples. In addition, in robotics, it is commonplace to err on the side of caution - Therefore, **If the alien is found to be TANGENT to either the WALLS or the BOUNDARIES it should be considered as AN INVALID configuration - i.e. should return True in the collision checking.** We have built in some assertions at the bottom of geometry.py to help with basic debugging, which can be executed by:

> **python3 geometry.py**

As mentioned before, once this class is properly implemented, you can also perform visual validation by running:

python3 mp5_6.py --human --map [MapName] --config maps/test_config.txt

The file maps/test_config.txt contains several maps. MapName is the name of the one you'd like to run. That is, MapName should be Test1, Test2, Test3, Test4, or NoSolutionMap.

Provided Code Skeleton and Deliverables

The code you need to get started is in this zip file. You will only have to modify and submit following file:

- geometry.py

Do not modify other provided code. It will make your code not runnable.

You can get additional help on the parameters for the main MP program by typing **python3 mp5_6.py -h** into your terminal.

Please upload **geometry.py** to gradescope.

Do not submit extra files to gradescope.