Assignment 1 Report - ROB521
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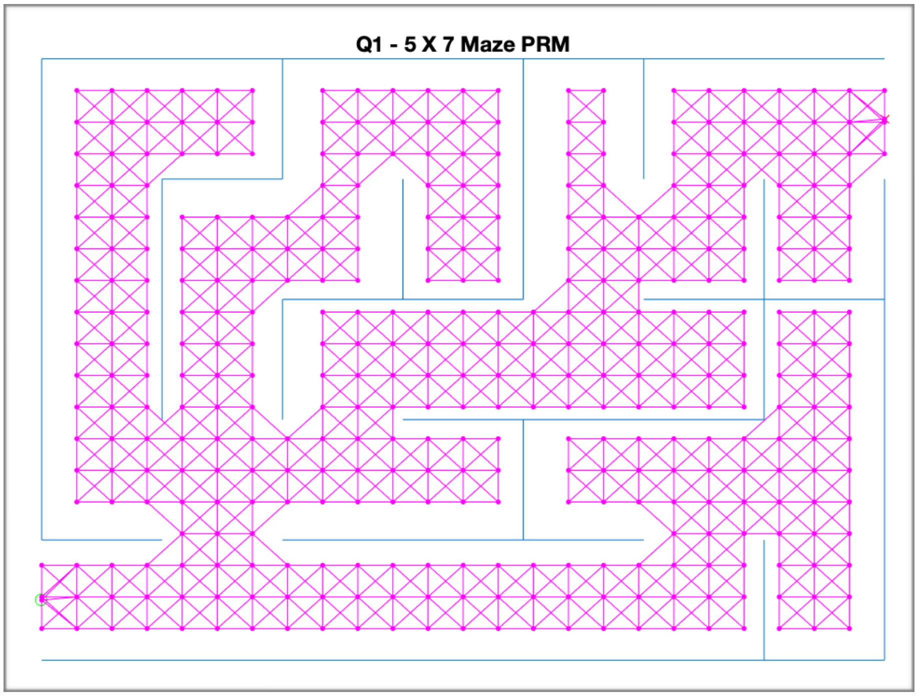
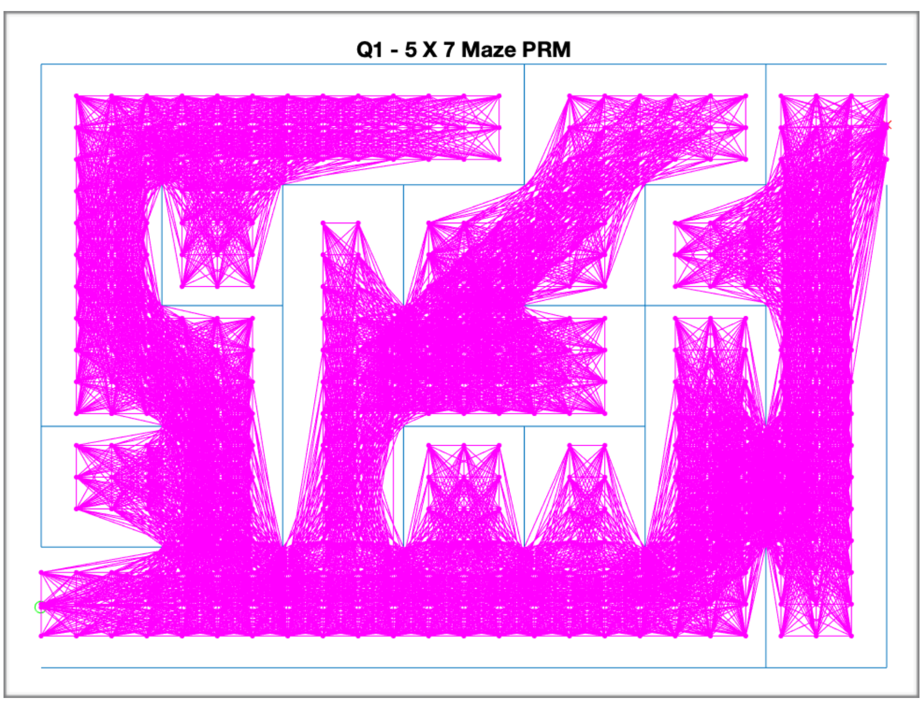
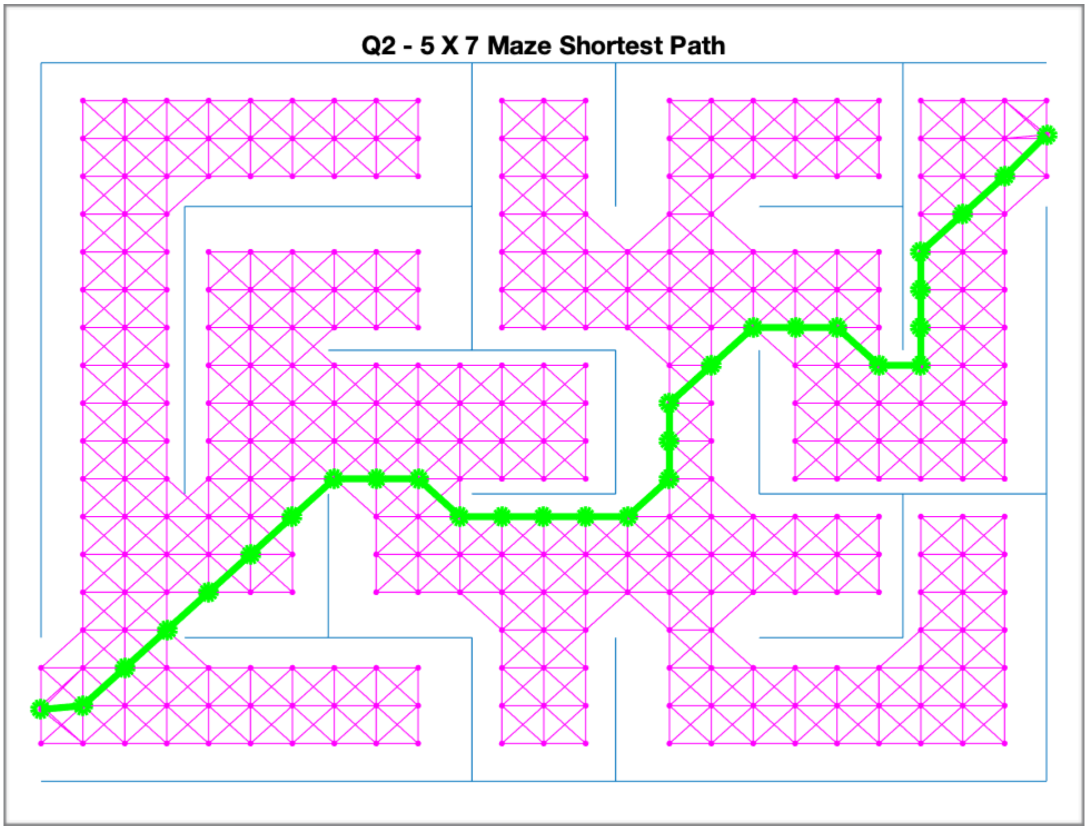
Q1: For the below graph, the nearest neighbour should be within 0.5 units. The time taken to generate the PRM was 0.28 seconds. The total number of edges are 1099.



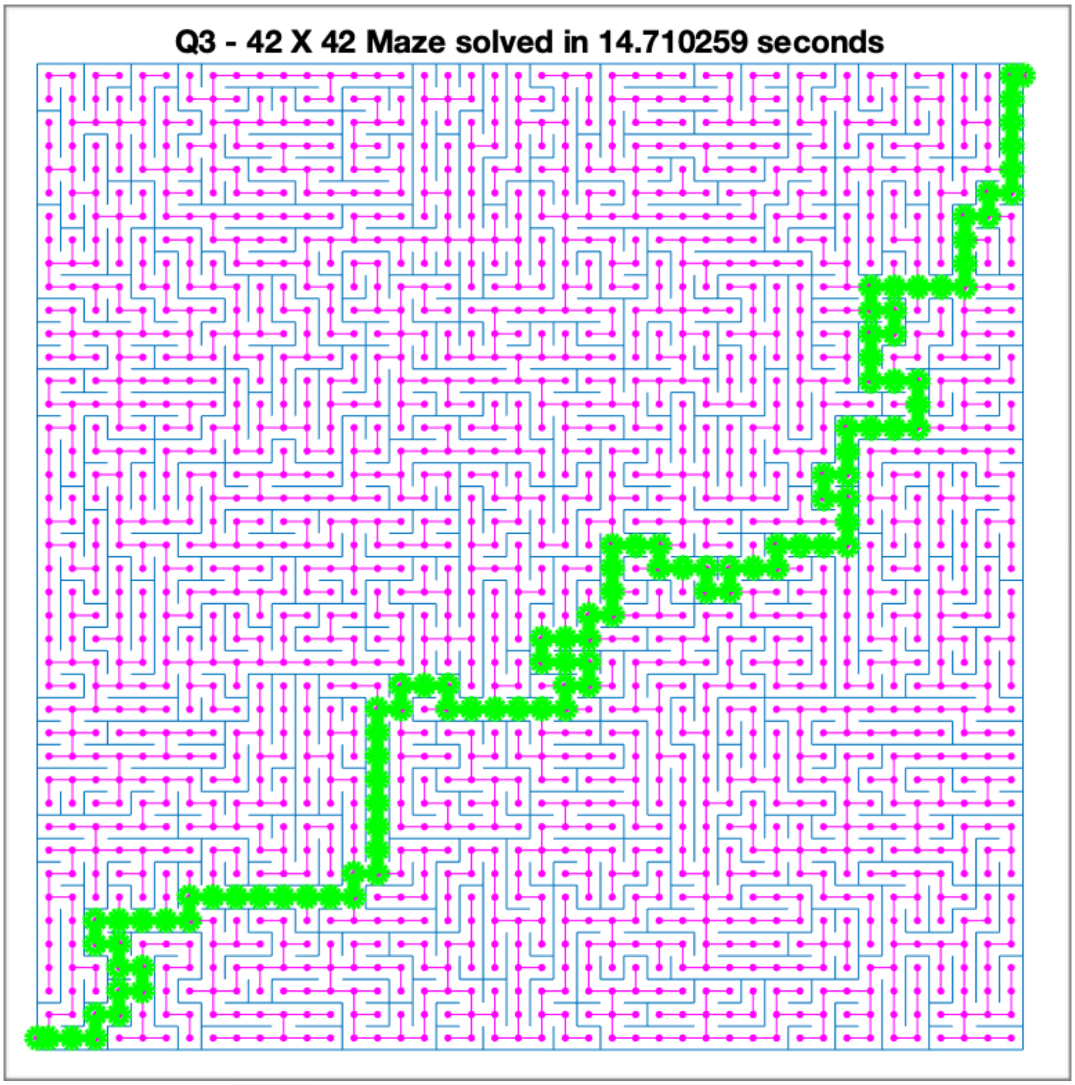
The below is a run for nearest neighbour less than 2 units. It took 2 seconds to generate PRM and total edges in the graph are 8531.



Q2: The shortest path is calculated using Dijkstra's algorithm. It took 1.6 seconds to calculate the shortest path of 9.7515 units.



Q3: For this part, a maze of size 42x42 is used. In order to find the shortest path under 20 seconds, I utilized the structure of the environment itself. Given that the maze edges are uniformly spaced, the points are also sampled in uniformly in both x and y direction with unit spaces. This way, it is guaranteed to have samples that are atleast 0.5 units away from any edge and we can do away with checking minimum distance of a sample point to every edge. Thus, all the sample points become milestones. The task was completed in 14.7 seconds.



```
% ======
% ROB521_assignment1.m
% ======
%
% This assignment will introduce you to the idea of motion planning
 for
% holonomic robots that can move in any direction and change direction
 of
% motion instantaneously.  Although unrealistic, it can work quite
 well for
% complex large scale planning.  You will generate mazes to plan
 through
% and employ the PRM algorithm presented in lecture as well as any
% variations you can invent in the later sections.
%
% There are three questions to complete (5 marks each):
%
%    Question 1: implement the PRM algorithm to construct a graph
%    connecting start to finish nodes.
%    Question 2: find the shortest path over the graph by implementing
 the
%    Dijkstra's or A* algorithm.
%    Question 3: identify sampling, connection or collision checking
%    strategies that can reduce runtime for mazes.
%
% Fill in the required sections of this script with your code, run it
 to
% generate the requested plots, then paste the plots into a short
 report
% that includes a few comments about what you've observed.  Append
 your
% version of this script to the report.  Hand in the report as a PDF
 file.
%
% requires: basic Matlab,
%
% S L Waslander, January 2022
%
clear; close all; clc;

% set random seed for repeatability if desired
% rng(1);

% ==========================
% Maze Generation
% ==========================
%
% The maze function returns a map object with all of the edges in the
 maze.
% Each row of the map structure draws a single line of the maze.  The
% function returns the lines with coordinates [x1 y1 x2 y2].
% Bottom left corner of maze is [0.5 0.5],
```

```
% Top right corner is [col+0.5 row+0.5]
%

row = 5; % Maze rows
col = 7; % Maze columns
map = maze(row,col); % Creates the maze
start = [0.5, 1.0]; % Start at the bottom left
finish = [col+0.5, row]; % Finish at the top right

h = figure(1);clf; hold on;
plot(start(1), start(2),'go')
plot(finish(1), finish(2),'rx')
show_maze(map,row,col,h); % Draws the maze
drawnow;

% ======================================================
% Question 1: construct a PRM connecting start and finish
% ======================================================
%
% Using 500 samples, construct a PRM graph whose milestones stay at
 least
% 0.1 units away from all walls, using the MinDist2Edges function
 provided for
% collision detection.  Use a nearest neighbour connection strategy
 and the
% CheckCollision function provided for collision checking, and find an
% appropriate number of connections to ensure a connection from  start
 to
% finish with high probability.


% variables to store PRM components
nS = 500;  % number of samples to try for milestone creation
milestones = [start; finish];  % each row is a point [x y] in feasible
 space
edges = [];  % each row is should be an edge of the form [x1 y1 x2 y2]

disp("Time to create PRM graph")
tic;
% ------insert your PRM generation code here-------
nR = 20;        % no. of points to sample along the row dimension
nC = 25;        % no. of points to sample along the column dimension
row_min = 0.5;
row_max = 5.5;
col_min = 0.5;
col_max = 7.5;
row_pts = linspace(row_min, row_max, nR);
col_pts = linspace(col_min, col_max, nC);

% milestone calculation
for x = col_pts
    for y = row_pts
        min_dis = MinDist2Edges([x, y], map);
        if min_dis>=0.1
```

```
            milestones = [milestones; [x, y]];
        end
    end
end

% build graph
nn_dist = 0.5;  % node that characterizes into nearest neighbour

for i = 1:length(milestones)
    for j = i+1:length(milestones)
        node1    = milestones(i,:);
        node2    = milestones(j,:);
        distance = norm(node1 - node2);

        if distance<=nn_dist
            [flag, ~] = CheckCollision(node1, node2, map);
            if flag==0   % no collisions
                edges = [edges; [node1(1), node1(2), node2(1),
 node2(2)]];
            end
        end
    end
end

% ------end of your PRM generation code -------
toc;

figure(1);
plot(milestones(:,1),milestones(:,2),'m.');
if (~isempty(edges))
    line(edges(:,1:2:3)', edges(:,2:2:4)','Color','magenta') % line
 uses [x1 x2 y1 y2]
end
str = sprintf('Q1 - %d X %d Maze PRM', row, col);
title(str);
drawnow;

print -dpng assignment1_q1.png
```

== Question 2: Find the shortest path over the PRM graph ==

Using an optimal graph search method (Dijkstra's or A*) , find the shortest path across the graph generated. Please code your own implementation instead of using any built in functions.

```
disp('Time to find shortest path');
tic;

% Variable to store shortest path
spath = []; % shortest path, stored as a milestone row index sequence

% ------insert your shortest path finding algorithm here-------
visited  = [start];     % list maintaining the visited nodes
```

```
pr_queue = [start 0];   % priority queue, the third column is cost-to-
come

% dictionary for backtracking
M = containers.Map('KeyType','int32', 'ValueType','any');

while ~isempty(pr_queue)
   top_element   = pr_queue(1,:);      % get top element
   cost_to_come  = top_element(3);     % cost-to-come for the node
   parent_node   = top_element(1:2);   % get the node
   pr_queue(1,:) = [];                 % pop top element

   if parent_node == finish
       disp('Reached goal!')
       break
   end

   neighbor_list = find_neighbours(parent_node, edges);
   for i = 1:length(neighbor_list)
       if ismember(neighbor_list(i,:),visited,'rows')==0
           visited = [visited; neighbor_list(i,:)];
           tot_cost_to_come = cost_to_come + norm(neighbor_list(i,:) -
 parent_node);

           % populate dictionary for backtracking
           cur_node_idx    = find_milestone_idx(neighbor_list(i,:),
 milestones);
           par_node_idx    = find_milestone_idx(parent_node,
 milestones);
           M(cur_node_idx) = [par_node_idx, tot_cost_to_come];

           % make appends to priority queue
           pr_queue = [pr_queue; neighbor_list(i,:) tot_cost_to_come];
       end
   end

   pr_queue = sortrows(pr_queue, 3);

end

spath    = [2];     % 2 is milestone index
x        = 2;
finish_p = M(2);
short_path = finish_p(2);
X = ['The shortest path is: ', num2str(short_path), ' units'];
disp(X)

start_idx  = 1;

while x~=start_idx
    parent = M(x);
    x      = int32(parent(1));
    spath  = [x; spath];
end
```

```
% ------end of shortest path finding algorithm-------
toc;

% plot the shortest path
figure(1);
for i=1:length(spath)-1
    plot(milestones(spath(i:i+1),1),milestones(spath(i:i
+1),2), 'go-', 'LineWidth',3);
end
str = sprintf('Q2 - %d X %d Maze Shortest Path', row, col);
title(str);
drawnow;

print -dpng assingment1_q2.png
```

== Question 3: find a faster way ==

Modify your milestone generation, edge connection, collision detection and/or shortest path methods to reduce runtime. What is the largest maze for which you can find a shortest path from start to goal in under 20 seconds on your computer? (Anything larger than 40x40 will suffice for full marks)

```
row = 42;
col = 42;
map = maze(row,col);
start = [0.5, 1.0];
finish = [col+0.5, row];
milestones = [start; finish];  % each row is a point [x y] in feasible
 space
edges = [];  % each row is should be an edge of the form [x1 y1 x2 y2]

h = figure(2);clf; hold on;
plot(start(1), start(2),'go')
plot(finish(1), finish(2),'rx')
show_maze(map,row,col,h); % Draws the maze
drawnow;

fprintf("Attempting large %d X %d maze... \n", row, col);
tic;
% ------insert your optimized algorithm here------

% ==================================================================
% Part I: Graph Generation
% ==================================================================

nR = row;           % no. of points to sample along the row dimension
nC = col;           % no. of points to sample along the column dimension
row_min = 1;
row_max = row;
col_min = 1;
col_max = col;
row_pts = linspace(row_min, row_max, nR);
```

```
col_pts = linspace(col_min, col_max, nC);

% milestone calculation; no need to check for collision
for x = col_pts
    for y = row_pts
        milestones = [milestones; [x, y]];
    end
end

% build graph
nn_dist = 1;  % node that characterizes into nearest neighbour

for i = 1:length(milestones)
    for j = i+1:length(milestones)
        node1    = milestones(i,:);
        node2    = milestones(j,:);
        distance = norm(node1 - node2);

        if distance<=nn_dist
            [flag, ~] = CheckCollision(node1, node2, map);
            if flag==0   % no collisions
                edges = [edges; [node1(1), node1(2), node2(1),
 node2(2)]];
            end
        end
    end
end

% =================================================================
% Part II: Finding shortest path
% =================================================================

spath = [];

visited  = [start];     % list maintaining the visited nodes
pr_queue = [start 0];   % priority queue, the third column is cost-to-
come

% dictionary for backtracking
M = containers.Map('KeyType','int32', 'ValueType','any');

while ~isempty(pr_queue)
   top_element   = pr_queue(1,:);      % get top element
   cost_to_come  = top_element(3);     % cost-to-come for the node
   parent_node   = top_element(1:2);   % get the node
   pr_queue(1,:) = [];                 % pop top element

   if parent_node == finish
       disp('Reached goal!')
       break
   end

   neighbor_list = find_neighbours(parent_node, edges);
   neighbor_size = size(neighbor_list);
```

```
    for i = 1:neighbor_size(1)
        if ismember(neighbor_list(i,:),visited,'rows')==0
            visited = [visited; neighbor_list(i,:)];
            tot_cost_to_come = cost_to_come + norm(neighbor_list(i,:) -
 parent_node);

            % populate dictionary for backtracking
            cur_node_idx    = find_milestone_idx(neighbor_list(i,:),
 milestones);
            par_node_idx    = find_milestone_idx(parent_node,
 milestones);
            M(cur_node_idx) = [par_node_idx, tot_cost_to_come];

            % make appends to priority queue
            pr_queue = [pr_queue; neighbor_list(i,:) tot_cost_to_come];
        end
    end

    pr_queue = sortrows(pr_queue, 3);

end

spath    = [2];     % 2 is milestone index
x        = 2;
finish_p = M(2);
short_path = finish_p(2);
X = ['The shortest path is: ', num2str(short_path), ' units'];
disp(X)

start_idx  = 1;

while x~=start_idx
    parent = M(x);
    x      = int32(parent(1));
    spath  = [x; spath];
end

% ------end of your optimized algorithm-------
dt = toc;

figure(2); hold on;
plot(milestones(:,1),milestones(:,2),'m.');
if (~isempty(edges))
    line(edges(:,1:2:3)', edges(:,2:2:4)','Color','magenta')
end
if (~isempty(spath))
    for i=1:length(spath)-1
        plot(milestones(spath(i:i+1),1),milestones(spath(i:i
+1),2), 'go-', 'LineWidth',3);
    end
end
str = sprintf('Q3 - %d X %d Maze solved in %f seconds', row, col, dt);
title(str);
```

```
print -dpng assignment1_q3.png
```

Custom function definitions

```
function nbors = find_neighbours(node, edge_list)
% given a node and the graph edge list, returns the neighbours of the
 node

    nbors     = [];   % neighbour list
    tot_edges = length(edge_list);

    for i = 1:tot_edges
        if edge_list(i,1:2)==node
            nbors = [nbors; edge_list(i,3:4)];
        elseif edge_list(i,3:4)==node
            nbors = [nbors; edge_list(i,1:2)];
        else
            continue
        end

    end
end

function index = find_milestone_idx(node, milestones)
% returns the index of the given node in the milestones list

    for i = 1:length(milestones)
        if milestones(i,:)==node
            index = i;
            return
        end
    end

end
```

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