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```
clear;
```

QUESTION 1:

```
% Function is at the bottom in the supporting code section
% function out = f(theta)

% Testing theta = pi/4
f(pi/4)

% Testing theta = -pi/4
f(-pi/4)

% Both are close to 0, so we are good
```

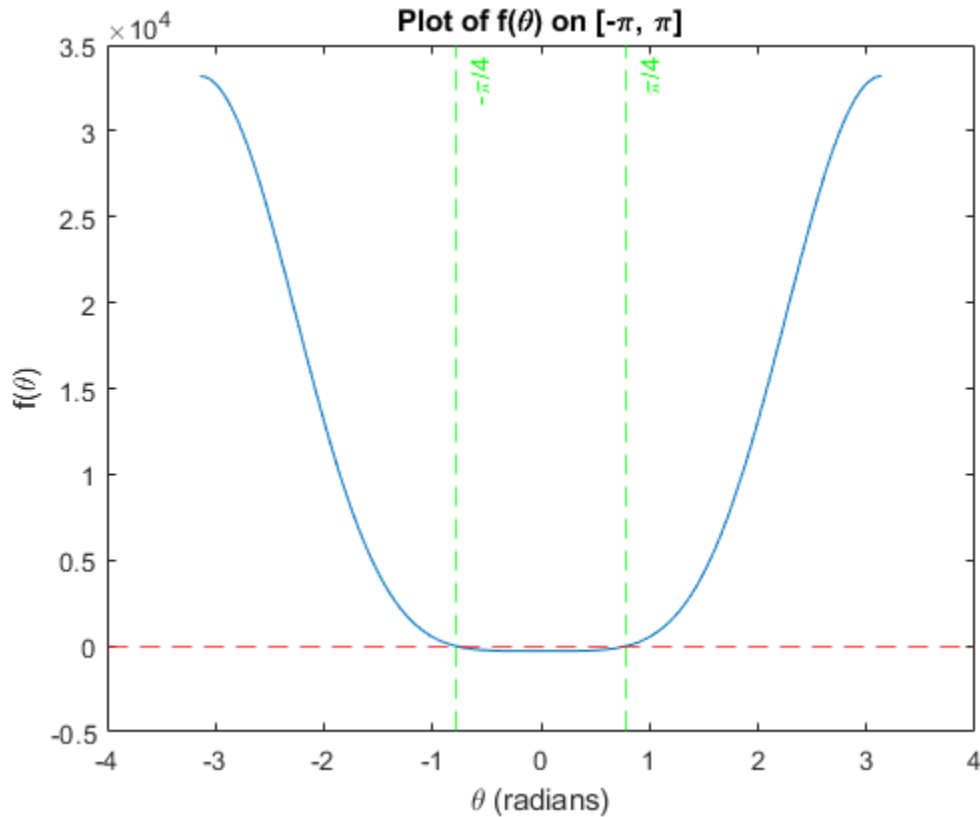
QUESTION 2:

```
% Plotting f(theta) on [-pi, pi]
theta_vals = -pi:0.01:pi;

f_vals = f(theta_vals);

figure(1)
plot(theta_vals, f_vals)
xlabel('\theta (radians)')
ylabel('f(\theta)')
title('Plot of f(\theta) on [-\pi, \pi]')
yline(0, '--r');
xline(pi/4, '--g', '\pi/4');
xline(-pi/4, '--g', '-\pi/4');
drawnow;

% Plot clearly shows that there are roots at +/- pi/4
```



QUESTION 3:

```
% Pose from Figure 1.15 (a)

% Connected to (0, 0) aka (x, y)
u1 = 1; v1 = 2;

% Connected to (x1, 0)
u2 = 2; v2 = 1;

% Connected to (x2, y2)
u3 = 2; v3 = 3;

x1 = 4; x2 = 0; y2 = 4;

figure(2)
plot([u1 u2 u3 u1], [v1 v2 v3 v1], 'r'); hold on % Platform triangle
plot([0 x1 x2], [0 0 y2], 'bo') % Base anchors
plot([u1 u2 u3], [v1 v2 v3], 'ro', 'MarkerSize', 8, 'MarkerFaceColor', 'r')
% Platform joints
plot([u1 0], [v1 0], 'k--') % p1
plot([u2 x1], [v2 0], 'k--') % p2
plot([u3 x2], [v3 y2], 'k--') % p3
title('Figure 1.15 (a)')
xlabel('x')
```

```

ylabel('y')
drawnow;

% Pose from Figure 1.15 (b)

% Connected to (0, 0) aka (x, y)
u1 = 2; v1 = 1;

% Connected to (x1, 0)
u2 = 3; v2 = 2;

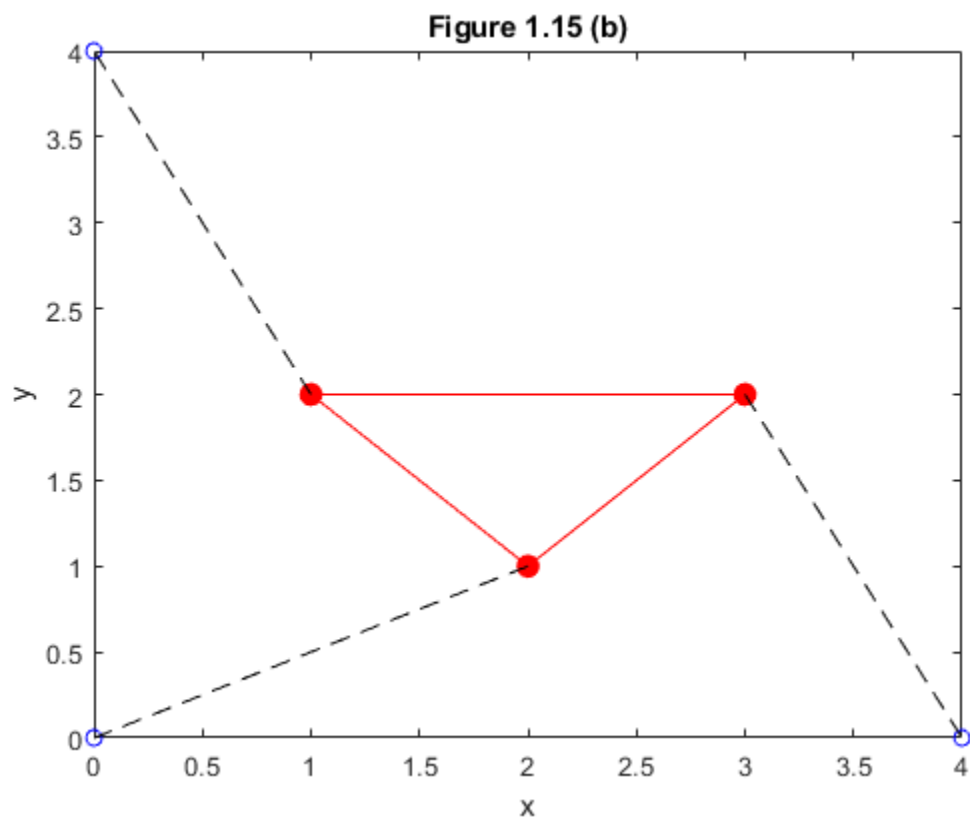
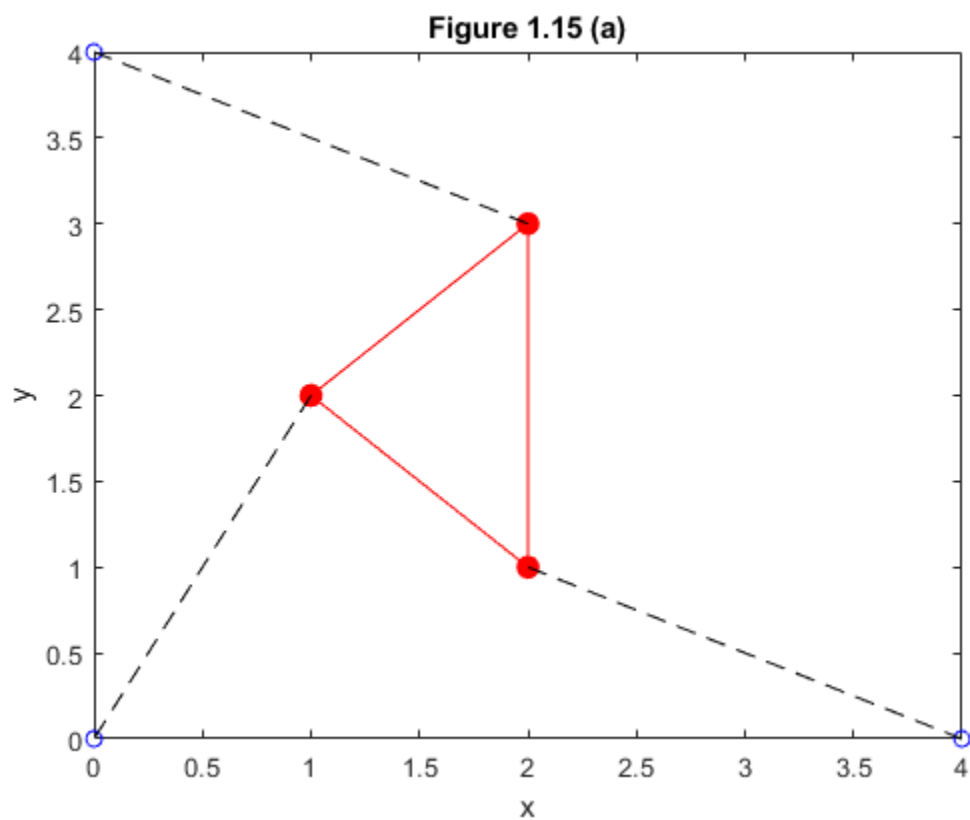
% Connected to (x2, y2)
u3 = 1; v3 = 2;

x1 = 4; x2 = 0; y2 = 4;

figure(3)
plot([u1 u2 u3 u1], [v1 v2 v3 v1], 'r'); hold on % Platform triangle
plot([0 x1 x2], [0 0 y2], 'bo') % Base anchors
plot([u1 u2 u3], [v1 v2 v3], 'ro', 'MarkerSize', 8, 'MarkerFaceColor', 'r')
% Platform joints
plot([u1 0], [v1 0], 'k--') % p1
plot([u2 x1], [v2 0], 'k--') % p2
plot([u3 x2], [v3 y2], 'k--') % p3
title('Figure 1.15 (b)')
xlabel('x')
ylabel('y')
drawnow;

% Here, we're just reproducing Figure 1.15 (a) and (b)

```



QUESTION 4:

```
% Forward kinematics is when we compute (x, y) and theta for each given p1,
% p2, and p3

% The inverse kinematic problem is when we find p1, p2, p3, given x, y, and
% theta

% The new f(theta) function is in the supporting functions section at the
% bottom (f_4(theta))

% Plotting f_4(theta) on [-pi, pi]
theta_vals = -pi:0.01:pi;

f_vals = f_variable_p2(theta_vals, 5); % p2=5

figure(4)
plot(theta_vals, f_vals)
xlabel('\theta (radians)')
ylabel('f(\theta)')
title('Plot of f(\theta) on [-\pi, \pi]')
yline(0, '--r');
drawnow;

% Finding the four theta values (guesses are from eyeballing the graph)
p2 = 5;
f_p2 = @(theta) f_variable_p2(theta, p2);

theta1 = fzero(f_p2, -0.72);
theta2 = fzero(f_p2, -0.33);
theta3 = fzero(f_p2, 1.14);
theta4 = fzero(f_p2, 2.11);
thetas = [theta1 theta2 theta3 theta4];

% From the above it appears that our roots are at:
% theta = -0.7208, -0.3310, 1.1437, and 2.1159 radians
figure(5)
plot(theta_vals, f_vals)
xlabel('\theta (radians)')
ylabel('f(\theta)')
title('Plot of f(\theta) on [-\pi, \pi] with roots')
yline(0, '--r');
xline(theta1, '--r', '-0.7208');
xline(theta2, '--r', '-0.3310');
xline(theta3, '--r', '1.1437');
xline(theta4, '--r', '2.1159');
drawnow;

% Since we're asked to solve the forward kinematics problem, we need to
% solve for x and y now (we just solved for theta)

% Finding the x and y coordinates for the four poses
% Created a new function at the bottom called
```

```

% forward_kinematics_variable_p2
[x_1 y_1] = forward_kinematics_variable_p2(theta1, p2);
[x_2 y_2] = forward_kinematics_variable_p2(theta2, p2);
[x_3 y_3] = forward_kinematics_variable_p2(theta3, p2);
[x_4 y_4] = forward_kinematics_variable_p2(theta4, p2);
xs = [x_1 x_2 x_3 x_4];
ys = [y_1 y_2 y_3 y_4];

% It was found that
% (x_1, y_1) = (-1.3784, 4.8063)
% (x_2, y_2) = (-0.9147, 4.9156)
% (x_3, y_3) = (4.4818, 2.2167)
% (x_4, y_4) = (4.5718, 2.0244)

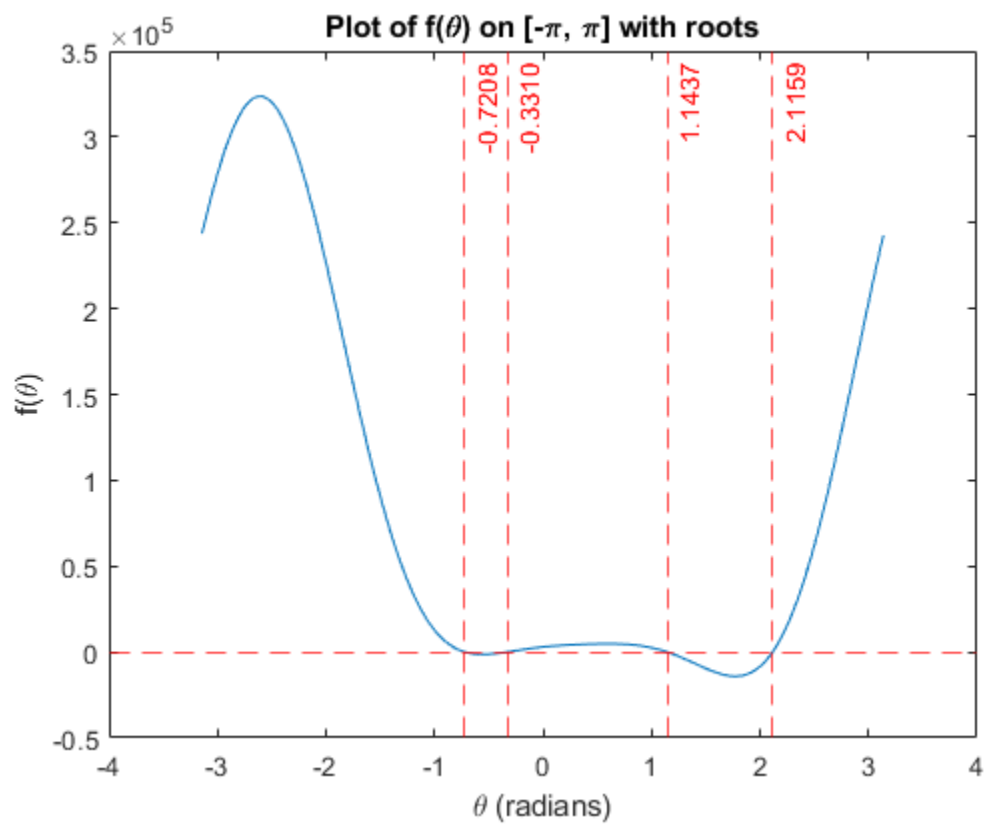
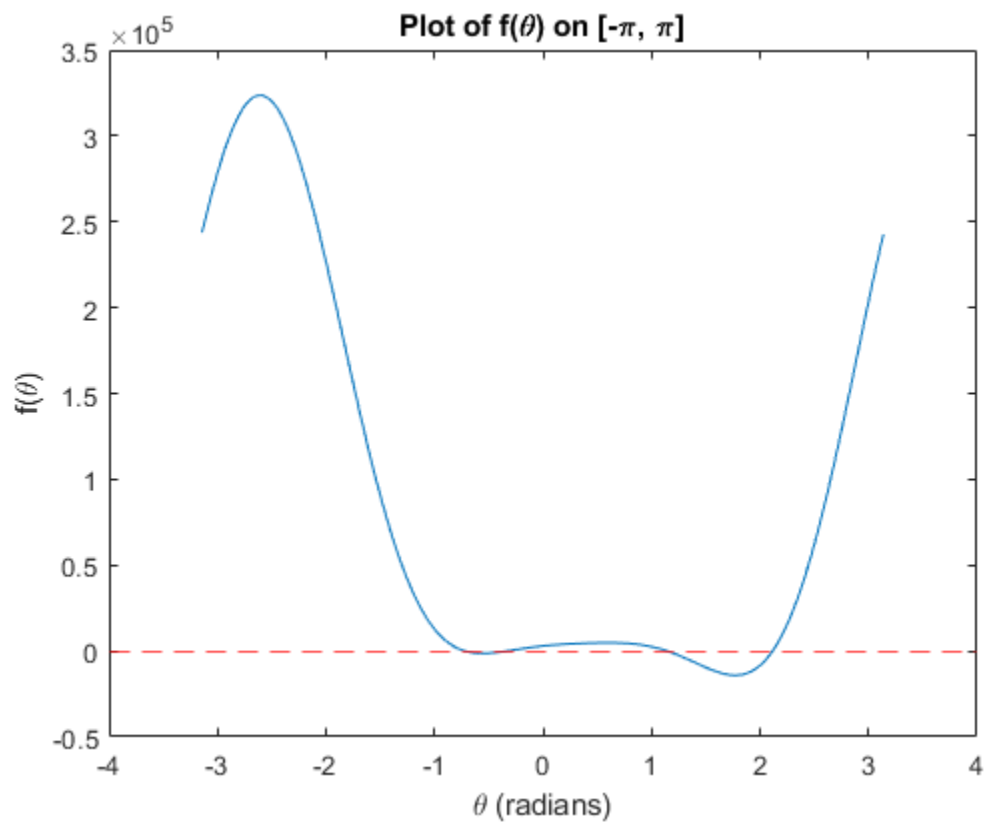
% Now we need to plot the four poses
% Helper function is in the supporting functions section

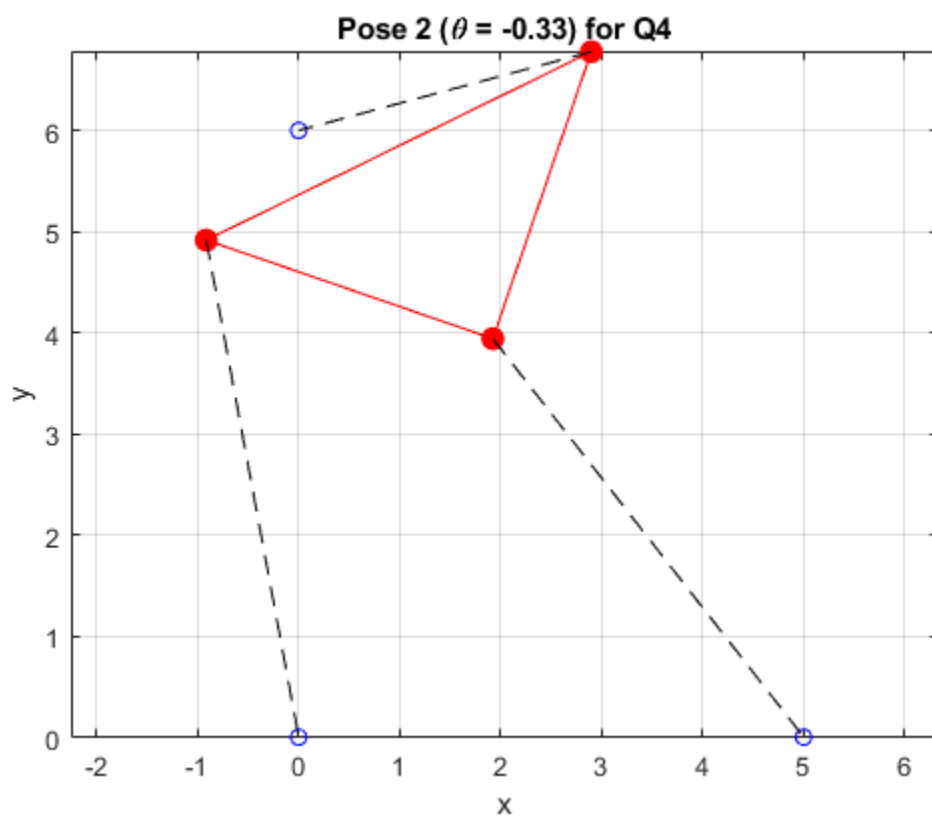
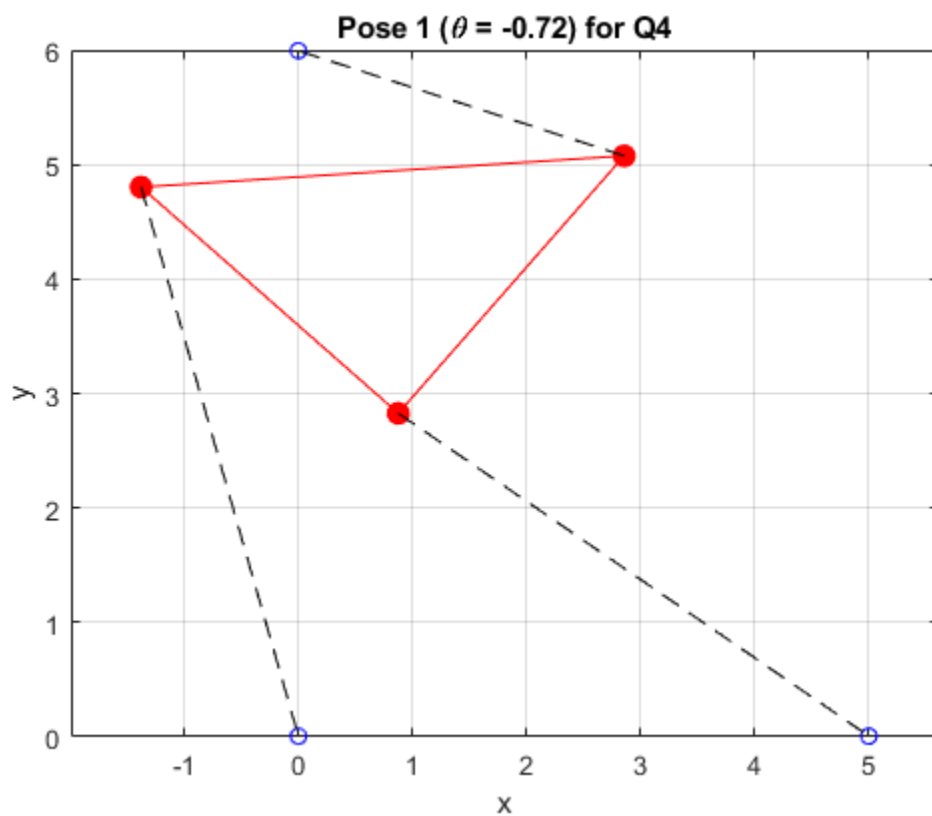
for i = 1:4
    draw_pose(5+i, xs(i), ys(i), thetas(i), 4);
    drawnow;
end

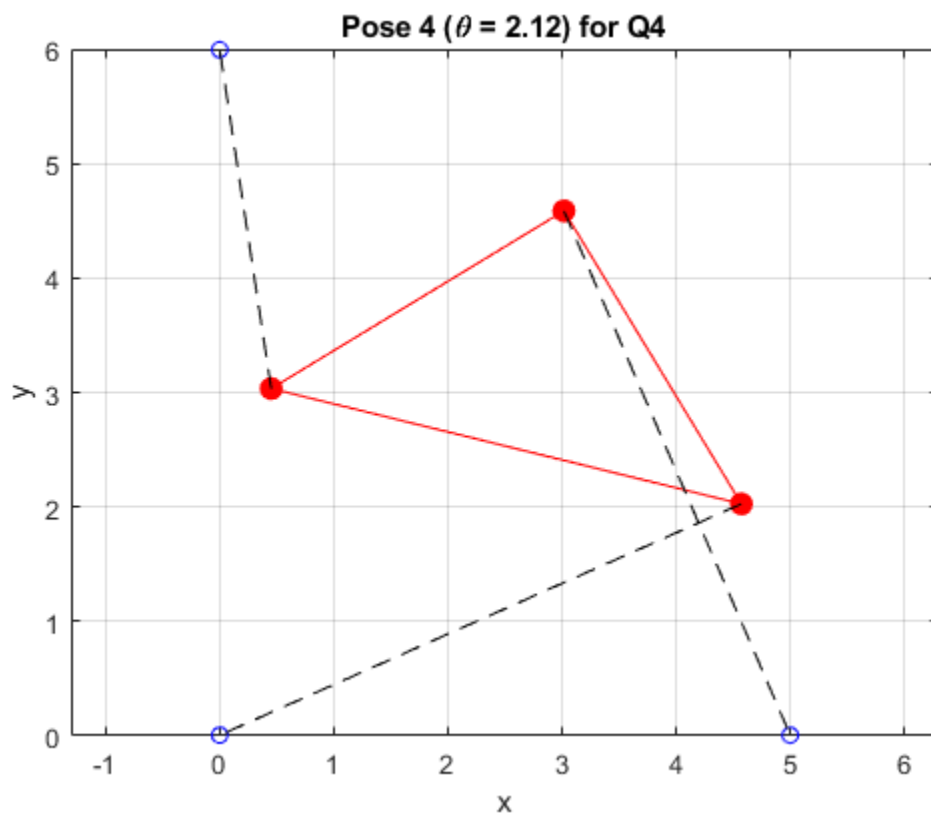
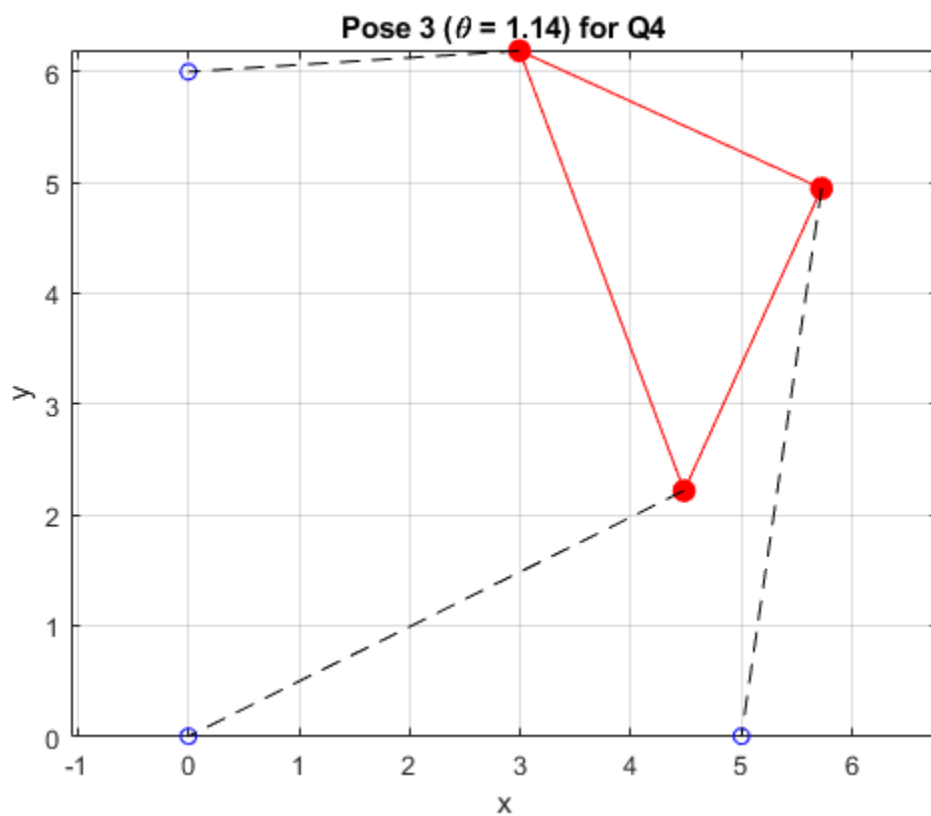
% The strut lengths are correct!!!

Pose 1: p1 = 5.0000, p2 = 5.0000, p3 = 3.0000
Pose 2: p1 = 5.0000, p2 = 5.0000, p3 = 3.0000
Pose 3: p1 = 5.0000, p2 = 5.0000, p3 = 3.0000
Pose 4: p1 = 5.0000, p2 = 5.0000, p3 = 3.0000

```







QUESTION 5:

```
% Here we are changing p2 to 7 and resolving problem 4

% Plotting f_5(theta) on [-pi, pi]
theta_vals = -pi:0.01:pi;

f_vals = f_variable_p2(theta_vals, 7); % p2=7

figure(10)
plot(theta_vals, f_vals)
xlabel('\theta (radians)')
ylabel('f(\theta)')
title('Plot of f(\theta) on [-\pi, \pi] for Question #5')
yline(0, '--r');
drawnow;

% The problem states that there are now six poses

% Finding the six theta values (guesses are from eyeballing the graph)
p2 = 7;
f_p2 = @(theta) f_variable_p2(theta, p2);

theta1 = fzero(f_p2, -0.68);
theta2 = fzero(f_p2, -0.36);
theta3 = fzero(f_p2, 0.03);
theta4 = fzero(f_p2, 0.44);
theta5 = fzero(f_p2, 0.97);
theta6 = fzero(f_p2, 2.5);

thetas = [theta1 theta2 theta3 theta4 theta5 theta6];

% From the above it appears that our roots are at:
% theta = -0.6732, -0.3547, 0.0378, 0.4589, 0.9777, and 2.5139 rad
figure(11)
plot(theta_vals, f_vals)
xlabel('\theta (radians)')
ylabel('f(\theta)')
title('Plot of f(\theta) on [-\pi, \pi] with roots')
yline(0, '--r');
xline(theta1, '--r', '-0.6732');
xline(theta2, '--r', '-0.3547');
xline(theta3, '--r', '0.0378');
xline(theta4, '--r', '0.4589');
xline(theta5, '--r', '0.9777');
xline(theta6, '--r', '2.5139');
drawnow;

% Since we're asked to solve the forward kinematics problem, we need to
% solve for x and y now (we just solved for theta)

% Finding the x and y coordinates for the four poses
[x_1 y_1] = forward_kinematics_variable_p2(theta1, p2);
```

```

[x_2 y_2] = forward_kinematics_variable_p2(theta2, p2);
[x_3 y_3] = forward_kinematics_variable_p2(theta3, p2);
[x_4 y_4] = forward_kinematics_variable_p2(theta4, p2);
[x_5 y_5] = forward_kinematics_variable_p2(theta5, p2);
[x_6 y_6] = forward_kinematics_variable_p2(theta6, p2);

xs = [x_1 x_2 x_3 x_4 x_5 x_6];
ys = [y_1 y_2 y_3 y_4 y_5 y_6];

% It was found that
% (x_1, y_1) = (-4.3148, 2.5264)
% (x_2, y_2) = (-4.8049, 1.3831)
% (x_3, y_3) = (-4.9490, 0.7121)
% (x_4, y_4) = (-0.8198, 4.9323)
% (x_5, y_6) = (2.3036, 4.4378)
% (x_5, y_6) = (3.2157, 3.8287)

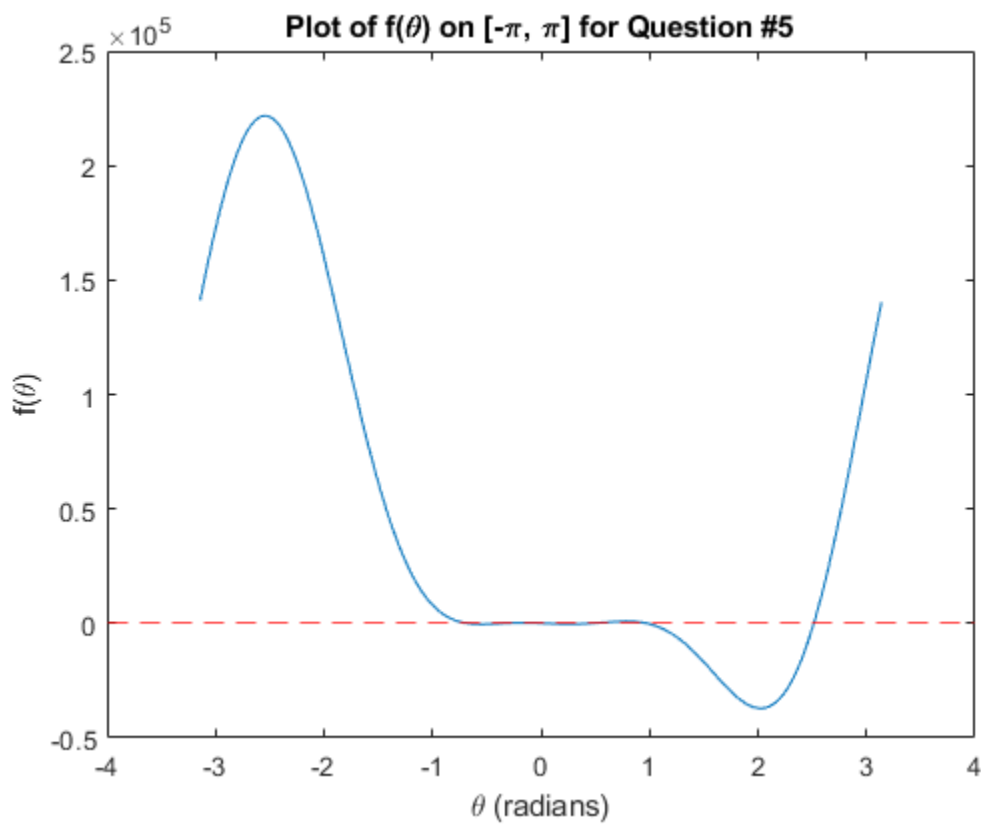
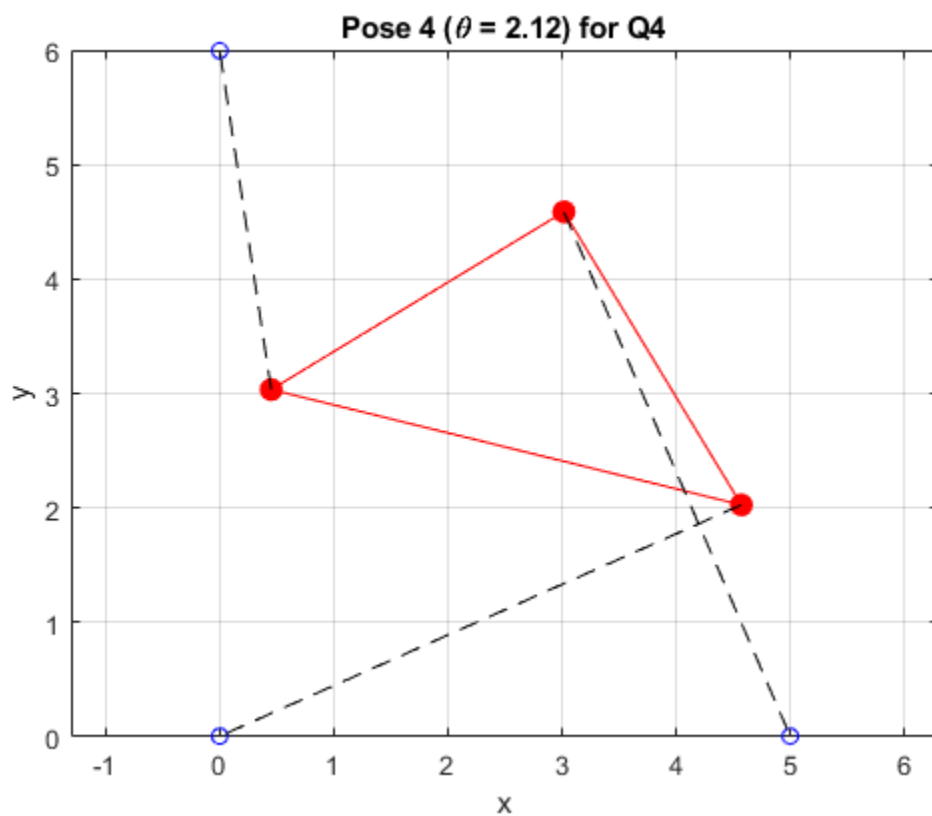
% Now we need to plot the four poses
% Helper function is in the supporting functions section

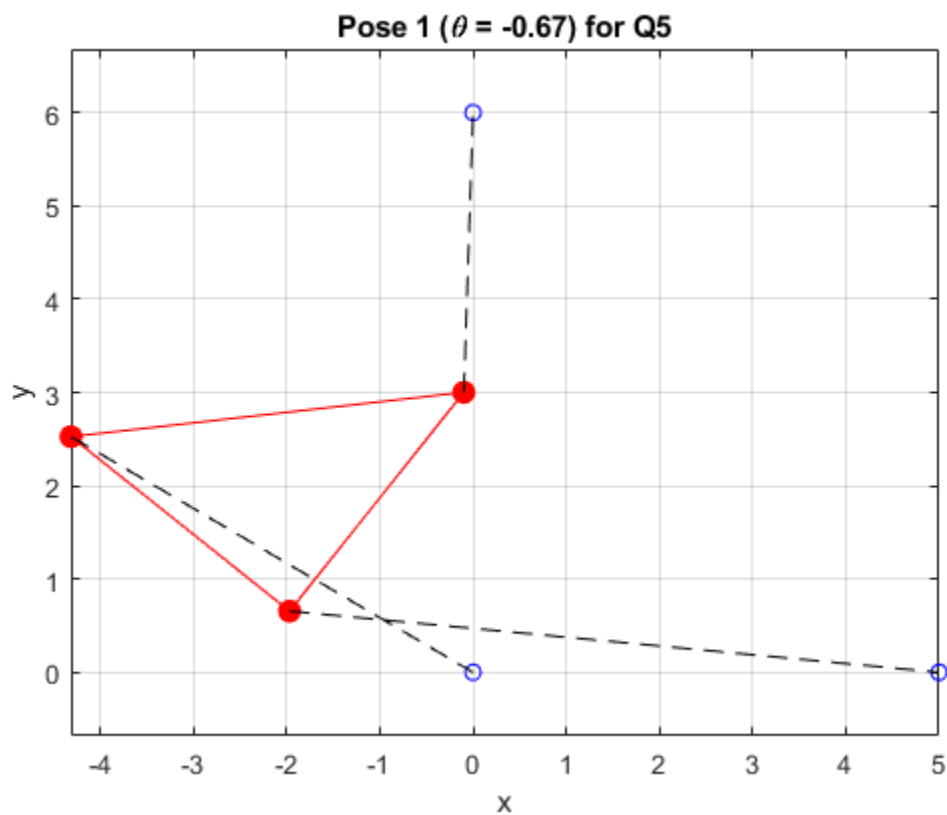
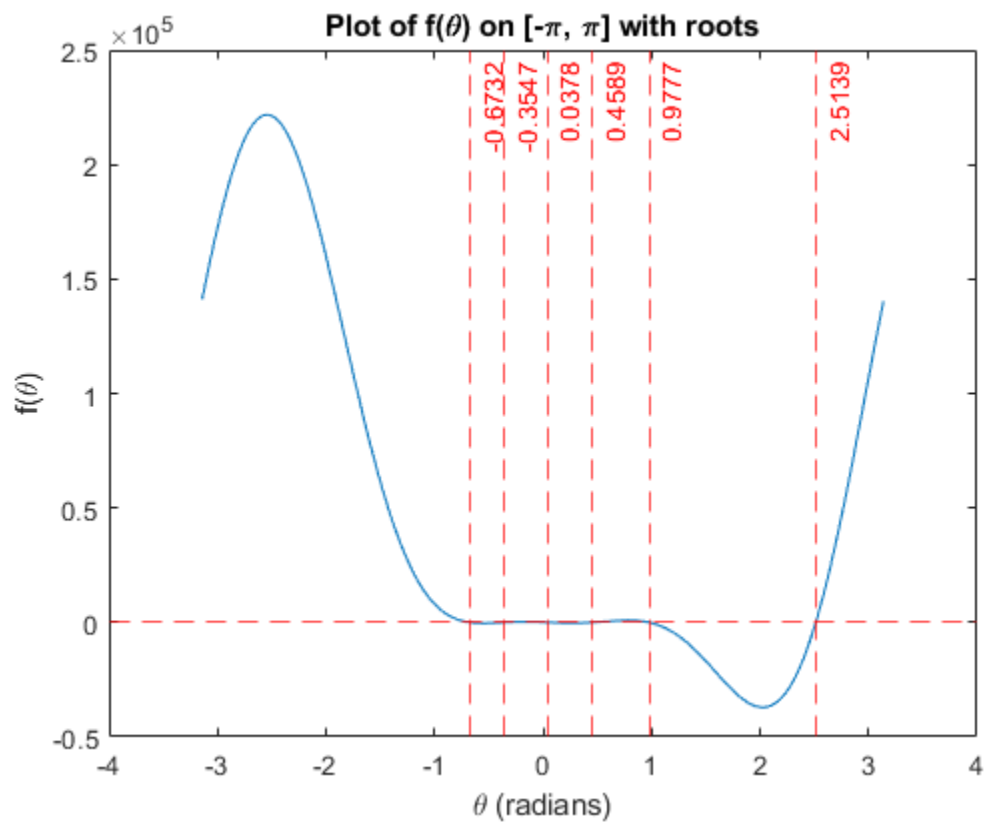
for i = 1:6
    draw_pose(11+i, xs(i), ys(i), thetas(i), 5);
    drawnow;
end

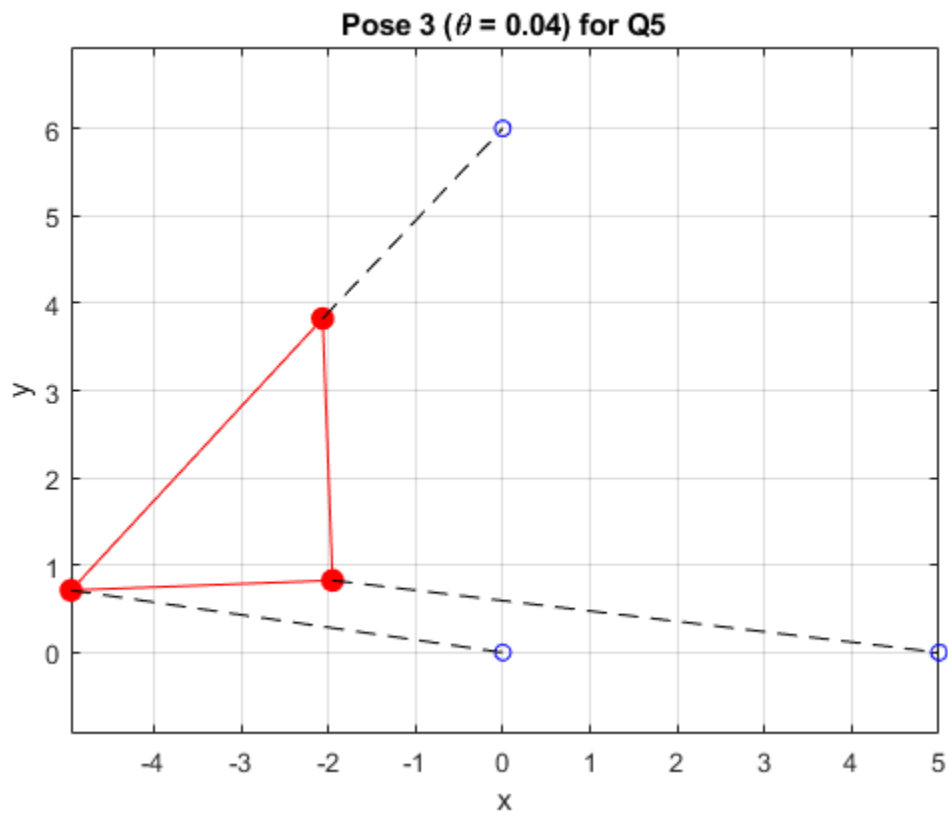
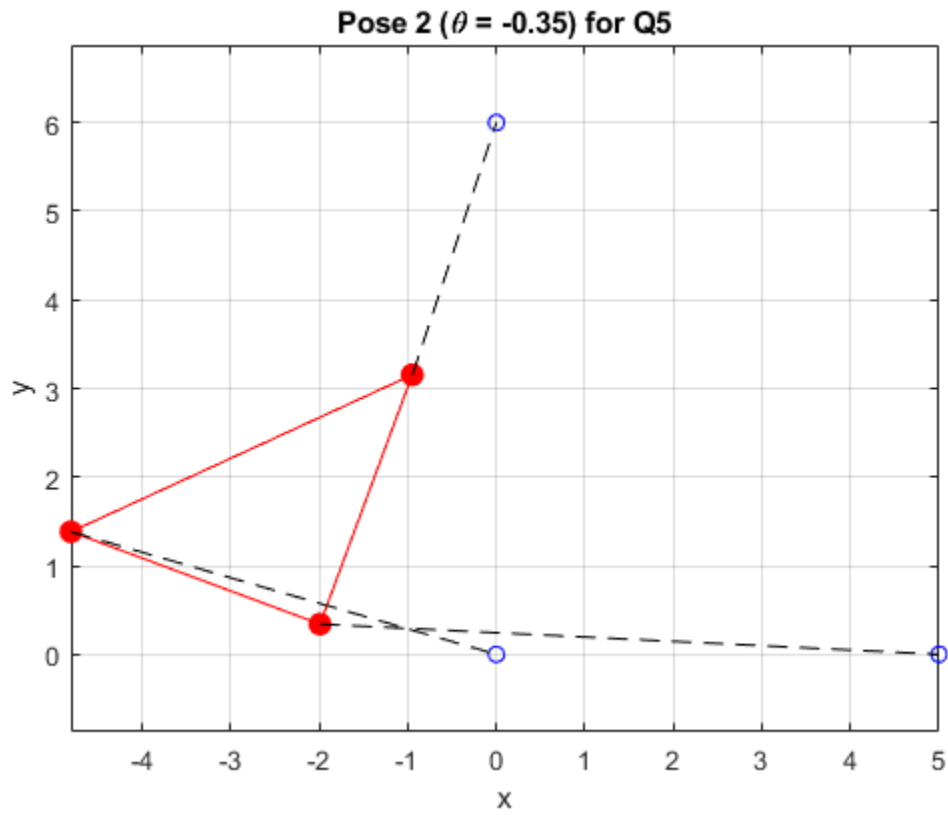
% The strut lengths are correct!!!

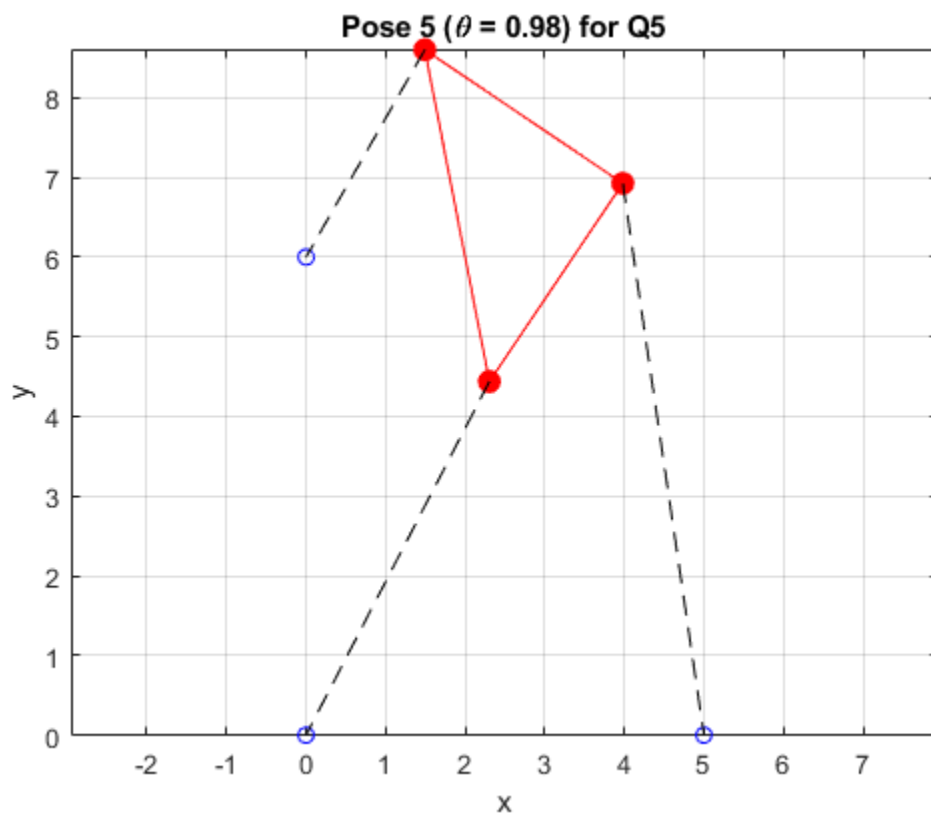
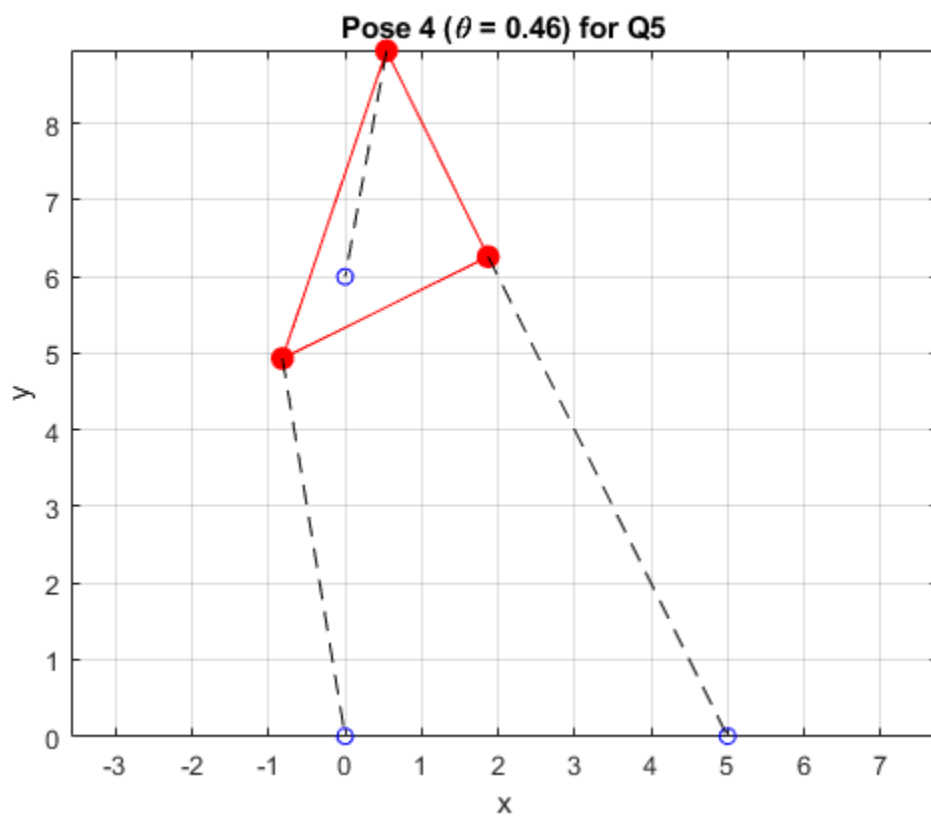
Pose 1: p1 = 5.0000, p2 = 7.0000, p3 = 3.0000
Pose 2: p1 = 5.0000, p2 = 7.0000, p3 = 3.0000
Pose 3: p1 = 5.0000, p2 = 7.0000, p3 = 3.0000
Pose 4: p1 = 5.0000, p2 = 7.0000, p3 = 3.0000
Pose 5: p1 = 5.0000, p2 = 7.0000, p3 = 3.0000
Pose 6: p1 = 5.0000, p2 = 7.0000, p3 = 3.0000

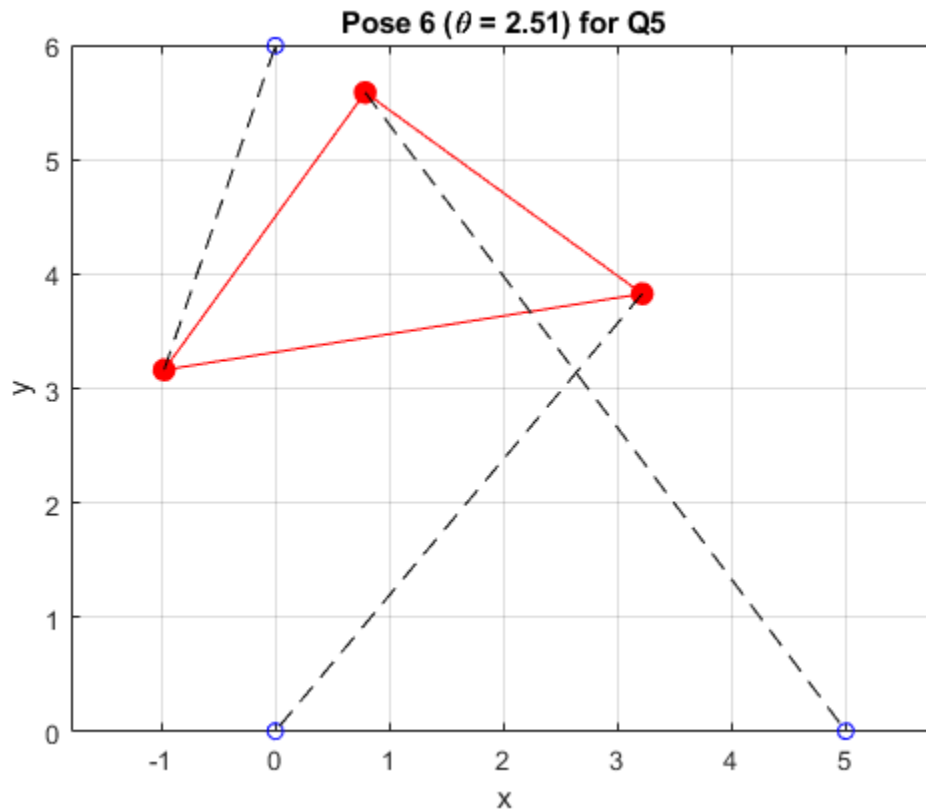
```











QUESTION 6:

% Through trial and error, it was found that a strut length of $p_2=4$, for
 % which there are only two poses

QUESTION 7:

QUESTION 8:

ALL FUNCTIONS SUPPORTING THIS CODE

```
% First f(theta) function
function out = f(theta)

    % Platform lengths
    L1 = 2;
    L2 = sqrt(2);
    L3 = sqrt(2);

    % Angle across from L1
    gamma = pi / 2;

    % Strut lengths
```

```

p1 = sqrt(5);
p2 = sqrt(5);
p3 = sqrt(5);

% Strut base positions
% Got these from Figure 1.15
x1 = 4;
x2 = 0;
y2 = 4;

A2 = L3 * cos(theta) - x1;
B2 = L3 * sin(theta);
A3 = L2 * (cos(theta) * cos(gamma) - sin(theta) * sin(gamma)) - x2;
B3 = L2 * (cos(theta) * sin(gamma) + sin(theta) * cos(gamma)) - y2;

N1 = B3 .* (p2^2 - p1^2 - A2.^2 - B2.^2) - B2 .* (p3^2 - p1^2 - A3.^2 -
B3.^2);
N2 = -A3 .* (p2^2 - p1^2 - A2.^2 - B2.^2) + A2 .* (p3^2 - p1^2 - A3.^2 -
B3.^2);

D = 2 * (A2 .* B3 - B2 .* A3);

out = N1.^2 + N2.^2 - p1.^2 * D.^2;

end

% f(theta) function with ability to change p2
function out = f_variable_p2(theta, p2)
L1 = 3; L2 = 3 * sqrt(2); L3 = 3;
gamma = pi / 4;
p1 = 5; p3 = 3;
x1 = 5; x2 = 0; y2 = 6;

A2 = L3 * cos(theta) - x1;
B2 = L3 * sin(theta);
A3 = L2 * (cos(theta) * cos(gamma) - sin(theta) * sin(gamma)) - x2;
B3 = L2 * (cos(theta) * sin(gamma) + sin(theta) * cos(gamma)) - y2;

N1 = B3 .* (p2^2 - p1^2 - A2.^2 - B2.^2) - B2 .* (p3^2 - p1^2 - A3.^2 -
B3.^2);
N2 = -A3 .* (p2^2 - p1^2 - A2.^2 - B2.^2) + A2 .* (p3^2 - p1^2 - A3.^2 -
B3.^2);
D = 2 * (A2 .* B3 - B2 .* A3);

out = N1.^2 + N2.^2 - p1.^2 * D.^2;

end

% Forward kinematics problem solver with variable p2
function [x, y] = forward_kinematics_variable_p2(theta, p2)

% Platform lengths
L1 = 3;
L2 = 3 * sqrt(2);
L3 = 3;

```

```

% Angle across from L1
gamma = pi / 4;

% Strut lengths
p1 = 5;
p3 = 3;

% Strut base positions
x1 = 5;
x2 = 0;
y2 = 6;

% Compute intermediate terms
A2 = L3 * cos(theta) - x1;
B2 = L3 * sin(theta);
A3 = L2 * (cos(theta) * cos(gamma) - sin(theta) * sin(gamma)) - x2;
B3 = L2 * (cos(theta) * sin(gamma) + sin(theta) * cos(gamma)) - y2;

% Numerators and denominator
N1 = B3 .* (p2^2 - p1^2 - A2.^2 - B2.^2) - B2 .* (p3^2 - p1^2 - A3.^2 -
B3.^2);
N2 = -A3 .* (p2^2 - p1^2 - A2.^2 - B2.^2) + A2 .* (p3^2 - p1^2 - A3.^2 -
B3.^2);
D = 2 * (A2 .* B3 - B2 .* A3);

% Solve for x and y
x = N1 / D;
y = N2 / D;

end

function draw_pose(fig_num, x, y, theta, question_number)
% Constants
L2 = 3 * sqrt(2);
L3 = 3;
gamma = pi/4;
x1 = 5; x2 = 0; y2 = 6;

% Triangle corner positions
u1 = x;
v1 = y;
u2 = x + L3 * cos(theta);
v2 = y + L3 * sin(theta);
u3 = x + L2 * cos(theta + gamma);
v3 = y + L2 * sin(theta + gamma);

% Compute strut lengths
p1 = norm([u1, v1] - [0, 0]);
p2 = norm([u2, v2] - [x1, 0]);
p3 = norm([u3, v3] - [x2, y2]);

% Plot

```

```

figure(fig_num)
plot([u1 u2 u3 u1], [v1 v2 v3 v1], 'r'); hold on
plot([0 x1 x2], [0 0 y2], 'bo')
plot([u1 u2 u3], [v1 v2 v3], 'ro', 'MarkerSize', 8, 'MarkerFaceColor',
'r')
plot([u1 0], [v1 0], 'k--') % p1
plot([u2 x1], [v2 0], 'k--') % p2
plot([u3 x2], [v3 y2], 'k--') % p3

% Pose label
if question_number == 4
    pose_index = fig_num - 5;
    title_str = sprintf('Pose %d (\\theta = %.2f) for Q4', pose_index,
theta);
elseif question_number == 5
    pose_index = fig_num - 11;
    title_str = sprintf('Pose %d (\\theta = %.2f) for Q5', pose_index,
theta);
else
    pose_index = fig_num;
    title_str = sprintf('Pose %d (\\theta = %.2f)', pose_index, theta);
end

title(title_str)
xlabel('x')
ylabel('y')
axis equal
grid on

% Print strut lengths
fprintf("Pose %d: p1 = %.4f, p2 = %.4f, p3 = %.4f\\n", pose_index, p1,
p2, p3);
end

ans =

-4.5475e-13

ans =

-4.5475e-13

```

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