AA 274A: Principles of Robot Autonomy I
Problem Set HW2

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1 A* Motion Planning

[ ]:
```
# The autoreload extension will automatically load in new code as you edit␣
↪files,
# so you don't need to restart the kernel every time
%load_ext autoreload
%autoreload 2
import numpy as np
import matplotlib.pyplot as plt
from P1_astar import DetOccupancyGrid2D, AStar
from utils import generate_planning_problem
```

1.1 Simple Environment

1.1.1 Workspace

(Try changing this and see what happens)

[ ]:
```
width = 10
height = 10
obstacles = [((6,7),(8,8)),((2,2),(4,3)),((2,5),(4,7)),((6,3),(8,5))]
occupancy = DetOccupancyGrid2D(width, height, obstacles)
```

1.1.2 Starting and final positions

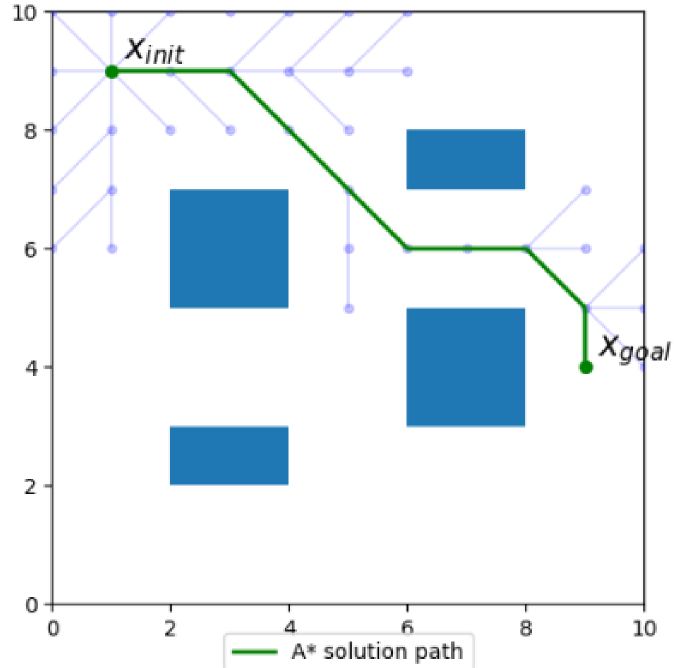
(Try changing these and see what happens)

[ ]:
```
x_init = (1, 9)
x_goal = (9, 4)
```

1.1.3 Run A* planning

[ ]:
```
astar = AStar((0, 0), (width, height), x_init, x_goal, occupancy)
if not astar.solve():
    print("No path found")
else:
    plt.rcParams['figure.figsize'] = [5, 5]
    astar.plot_path()
```

```
astar.plot_tree()
```



1.2 Random Cluttered Environment

1.2.1 Generate workspace, start and goal positions

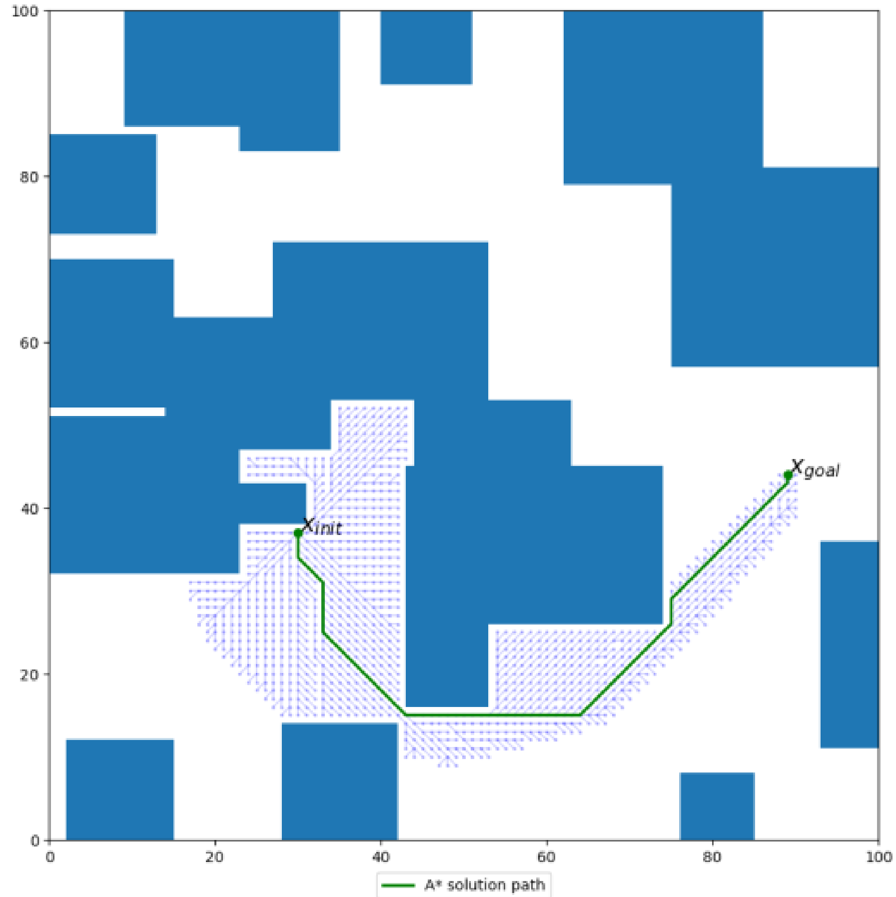
(Try changing these and see what happens)

```
[ ]: width = 100
height = 100
num_obs = 25
min_size = 5
max_size = 30

occupancy, x_init, x_goal = generate_planning_problem(width, height, num_obs,␣
↪min_size, max_size)
```

1.2.2 Run A* planning

[ ]:
```
astar = AStar((0, 0), (width, height), x_init, x_goal, occupancy)
if not astar.solve():
    print("No path found")
else:
    plt.rcParams['figure.figsize'] = [10, 10]
    astar.plot_path()
    astar.plot_tree(point_size=2)
```



[ ]:
```
```

1 RRT Sampling-Based Motion Planning

[ ]:
```
# The autoreload extension will automatically load in new code as you edit␣
↪files,
# so you don't need to restart the kernel every time
%load_ext autoreload
%autoreload 2

import numpy as np
import matplotlib.pyplot as plt
from P2_rrt import *

plt.rcParams['figure.figsize'] = [8, 8] # Change default figure size
```

```
The autoreload extension is already loaded. To reload it, use:
  %reload_ext autoreload
```

1.0.1 Set up workspace

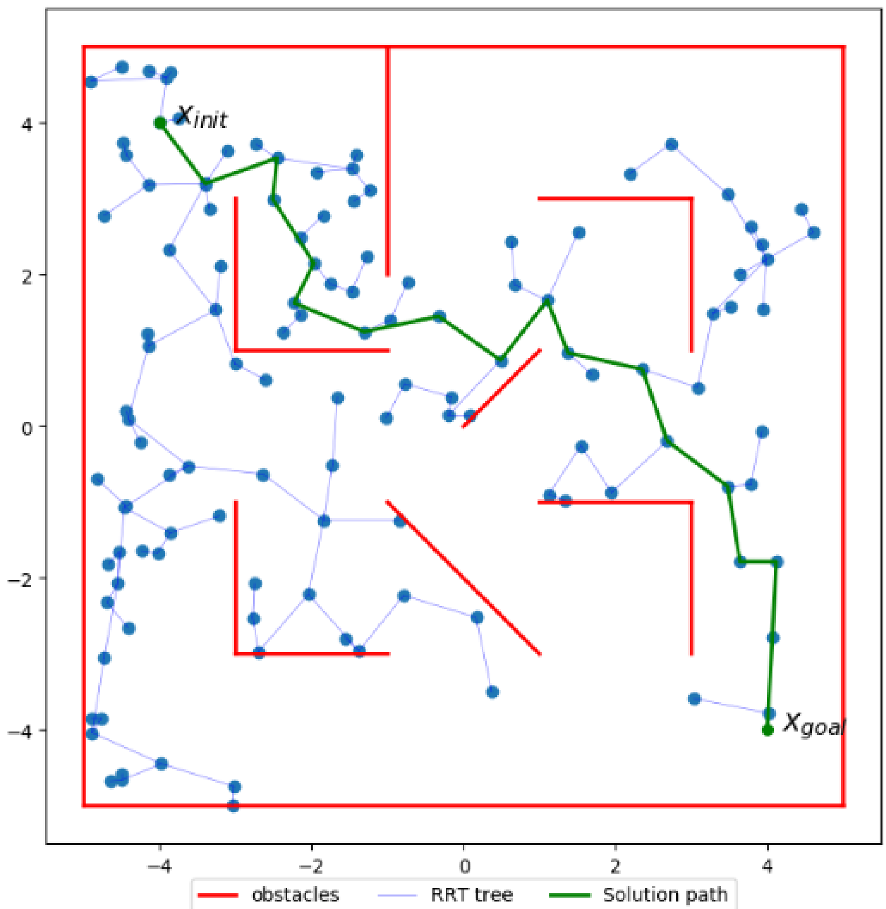
[ ]:
```
MAZE = np.array([
    (( 5, 5), (-5, 5)),
    ((-5, 5), (-5,-5)),
    ((-5,-5), ( 5,-5)),
    (( 5,-5), ( 5, 5)),
    ((-3,-3), (-3,-1)),
    ((-3,-3), (-1,-3)),
    (( 3, 3), ( 3, 1)),
    (( 3, 3), ( 1, 3)),
    (( 1,-1), ( 3,-1)),
    (( 3,-1), ( 3,-3)),
    ((-1, 1), (-3, 1)),
    ((-3, 1), (-3, 3)),
    ((-1,-1), ( 1,-3)),
    ((-1, 5), (-1, 2)),
    (( 0, 0), ( 1, 1))
])
```

```
# try changing these!
x_init = [-4,4] # reset to [-4,4] when saving results for submission
x_goal = [4,-4] # reset to [4,-4] when saving results for submission
```

1.1 Geometric Planning

[ ]:
```
grrt = GeometricRRT([-5,-5], [5,5], x_init, x_goal, MAZE)
grrt.solve(1.0, 2000)
```

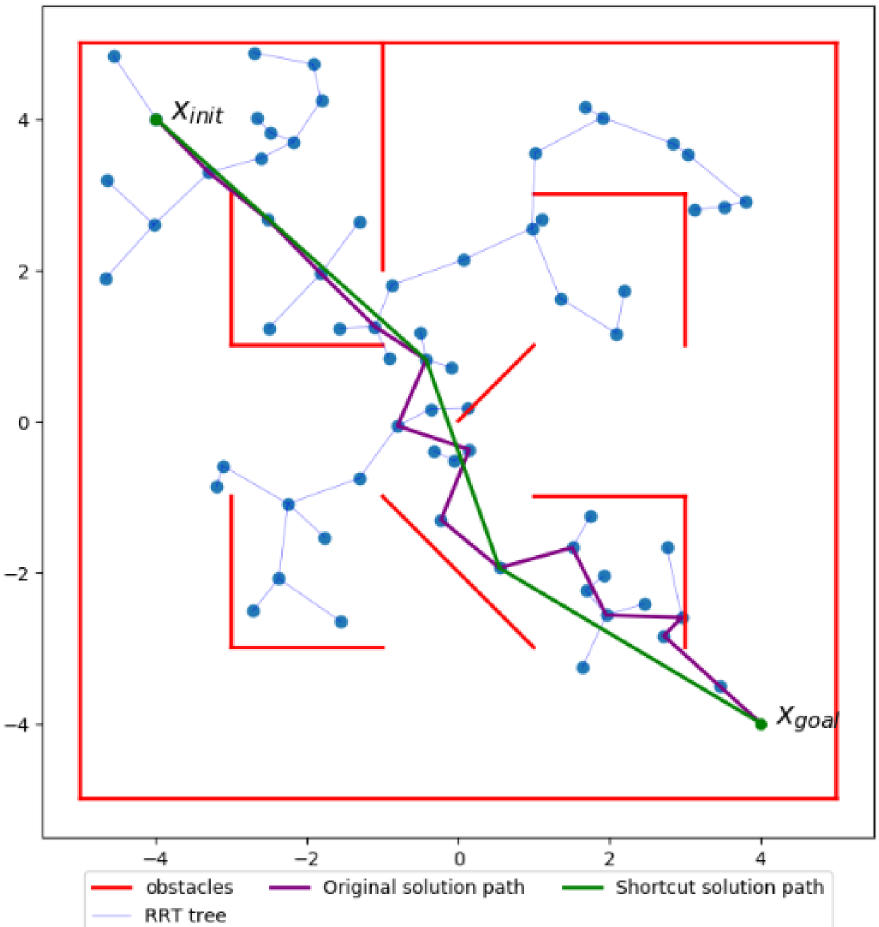
[ ]:
```
True
```



1.1.1 Adding shortcutting

```
[ ]: grrt.solve(1.0, 2000, shortcut=True)
```

```
[ ]: True
```

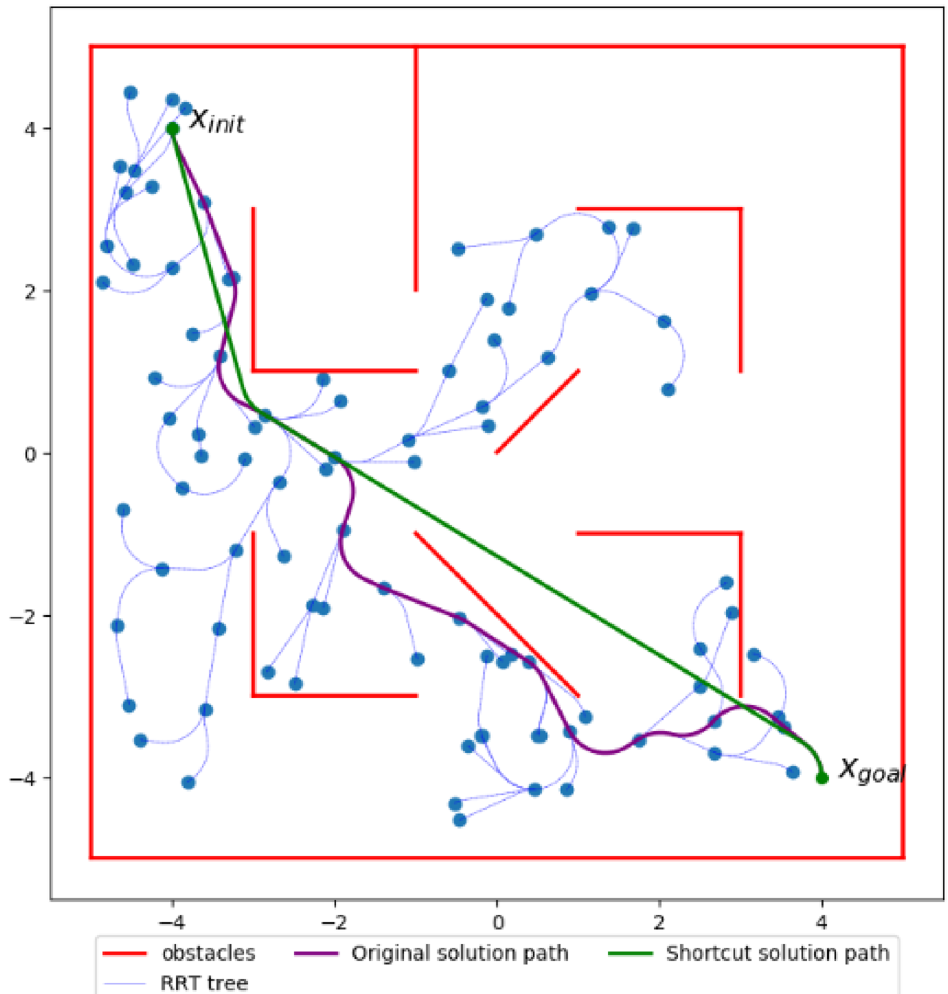


1.2 Dubins Car Planning

[ ]:
```
x_init = [-4,4, 3*np.pi/2]
x_goal = [4,-4, 3*np.pi/2]

drrt = DubinsRRT([-5,-5,0], [5,5,2*np.pi], x_init, x_goal, MAZE, .5)
drrt.solve(1.0, 1000, shortcut=True)
```

[ ]:
```
True
```



```
[ ]: # The autoreload extension will automatically load in new code as you edit␣
      ↪files,
     # so you don't need to restart the kernel every time
     %load_ext autoreload
     %autoreload 2

     import numpy as np
     from P1_astar import AStar
     from P2_rrt import *
     from P3_traj_planning import compute_smoothed_traj, modify_traj_with_limits,␣
      ↪SwitchingController
     import matplotlib.pyplot as plt
     from HW1.P1_differential_flatness import *
     from HW1.P2_pose_stabilization import *
     from HW1.P3_trajectory_tracking import *
     from utils import generate_planning_problem
     from HW1.utils import simulate_car_dyn

     plt.rcParams['figure.figsize'] = [14, 14] # Change default figure size
```

```
The autoreload extension is already loaded. To reload it, use:
  %reload_ext autoreload
```

0.0.1 Generate workspace, start and goal positions

```
[ ]: width = 100
     height = 100
     num_obs = 25
     min_size = 5
     max_size = 30

     occupancy, x_init, x_goal = generate_planning_problem(width, height, num_obs,␣
      ↪min_size, max_size)
```

0.0.2 Solve A* planning problem

[ ]:
```python
astar = AStar((0, 0), (width, height), x_init, x_goal, occupancy)
if not astar.solve():
    print("No path found")
```

0.1 Smooth Trajectory Generation

0.1.1 Trajectory parameters

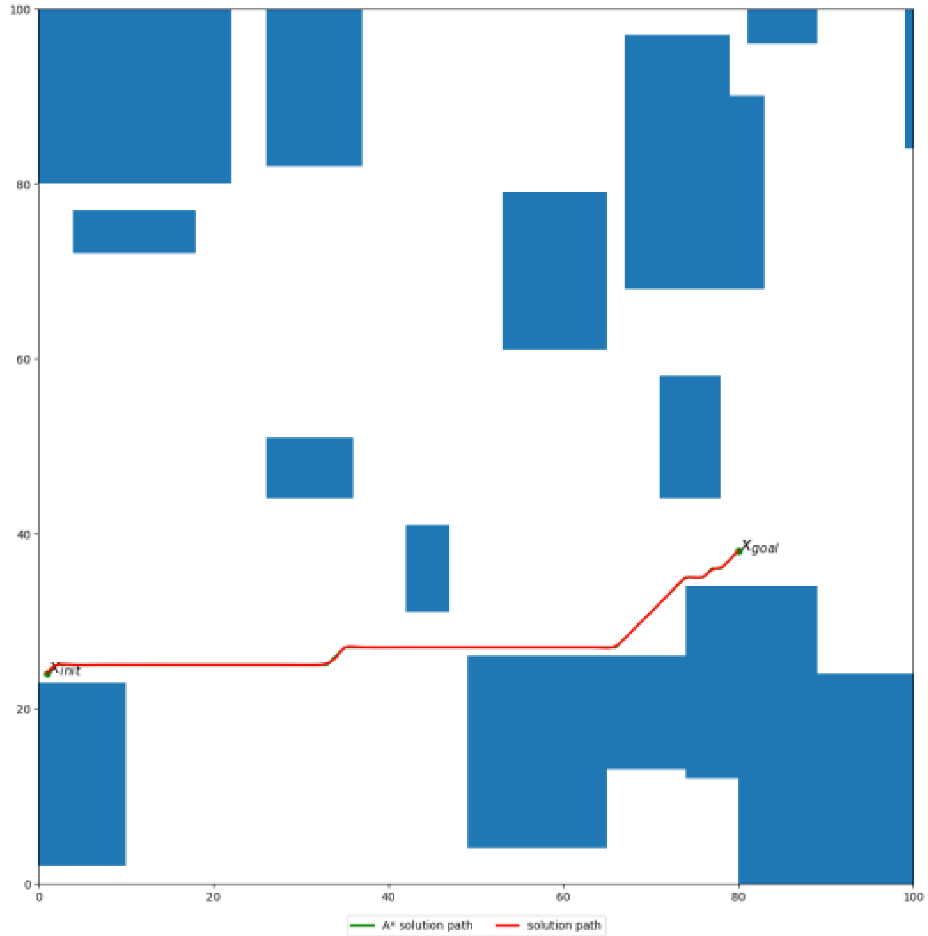
(Try changing these and see what happens)

[ ]:
```python
V_des = 0.3   # Nominal velocity
alpha = 0.1    # Smoothness parameter
dt = 0.05
k_spline = 3
```

0.1.2 Generate smoothed trajectory

[ ]:
```python
t_smoothed, traj_smoothed = compute_smoothed_traj(astar.path, V_des, k_spline,␣
 ↪alpha, dt)

fig = plt.figure()
astar.plot_path(fig.number)
def plot_traj_smoothed(traj_smoothed):
    plt.plot(traj_smoothed[:,0], traj_smoothed[:,1], color="red", linewidth=2,␣
 ↪label="solution path", zorder=10)
plot_traj_smoothed(traj_smoothed)
plt.legend(loc='upper center', bbox_to_anchor=(0.5, -0.03), fancybox=True,␣
 ↪ncol=3)
plt.show()
```



0.2 Control-Feasible Trajectory Generation and Tracking

0.2.1 Robot control limits

[ ]:
```
V_max = 0.5 # max speed
om_max = 1 # max rotational speed
```

0.2.2 Tracking control gains

Tune these as needed to improve tracking performance.

[ ]:
```
kpx = 1
kpy = 1
```

```
kdx = 0.5
kdy = 0.5
```

0.2.3 Generate control-feasible trajectory

[ ]:
```
t_new, V_smooth_scaled, om_smooth_scaled, traj_smooth_scaled = modify_traj_with_limits(traj_smoothed, t_smoothed, V_max, om_max, dt)
```

0.2.4 Create trajectory controller and load trajectory

[ ]:
```
traj_controller = TrajectoryTracker(kpx=kpx, kpy=kpy, kdx=kdx, kdy=kdy, V_max=V_max, om_max=om_max)
traj_controller.load_traj(t_new, traj_smooth_scaled)
```

0.2.5 Set simulation input noise

(Try changing this and see what happens)

[ ]:
```
noise_scale = 0.05
```

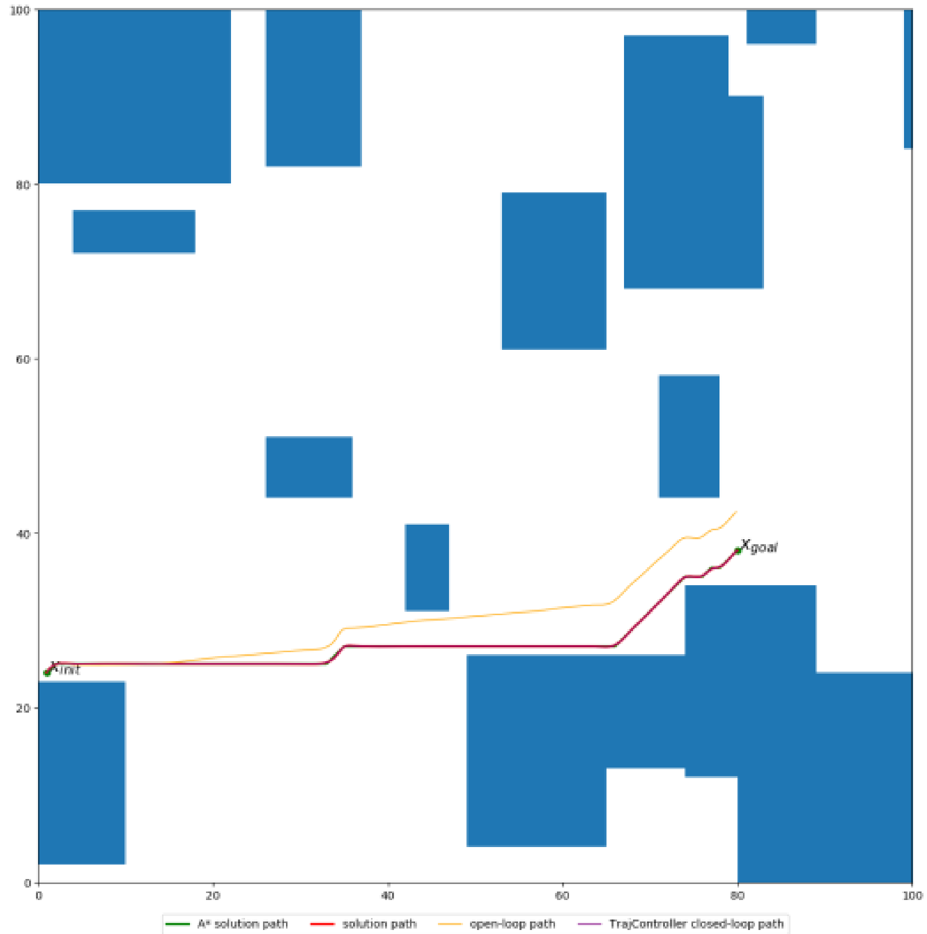
0.2.6 Simulate closed-loop tracking of smoothed trajectory, compare to open-loop

[ ]:
```
tf_actual = t_new[-1]
times_cl = np.arange(0, tf_actual, dt)
s_0 = State(x=x_init[0], y=x_init[1], V=V_max, th=traj_smooth_scaled[0,2])
s_f = State(x=x_goal[0], y=x_goal[1], V=V_max, th=traj_smooth_scaled[-1,2])

actions_ol = np.stack([V_smooth_scaled, om_smooth_scaled], axis=-1)
states_ol, ctrl_ol = simulate_car_dyn(s_0.x, s_0.y, s_0.th, times_cl, actions=actions_ol, noise_scale=noise_scale)
states_cl, ctrl_cl = simulate_car_dyn(s_0.x, s_0.y, s_0.th, times_cl, controller=traj_controller, noise_scale=noise_scale)

fig = plt.figure()
astar.plot_path(fig.number)
plot_traj_smoothed(traj_smoothed)
def plot_traj_ol(states_ol):
    plt.plot(states_ol[:,0],states_ol[:,1], color="orange", linewidth=1, label="open-loop path", zorder=10)
def plot_traj_cl(states_cl):
    plt.plot(states_cl[:,0], states_cl[:,1], color="purple", linewidth=1, label="TrajController closed-loop path", zorder=10)
plot_traj_ol(states_ol)
plot_traj_cl(states_cl)
plt.legend(loc='upper center', bbox_to_anchor=(0.5, -0.03), fancybox=True, ncol=4)
```

```
plt.show()
```



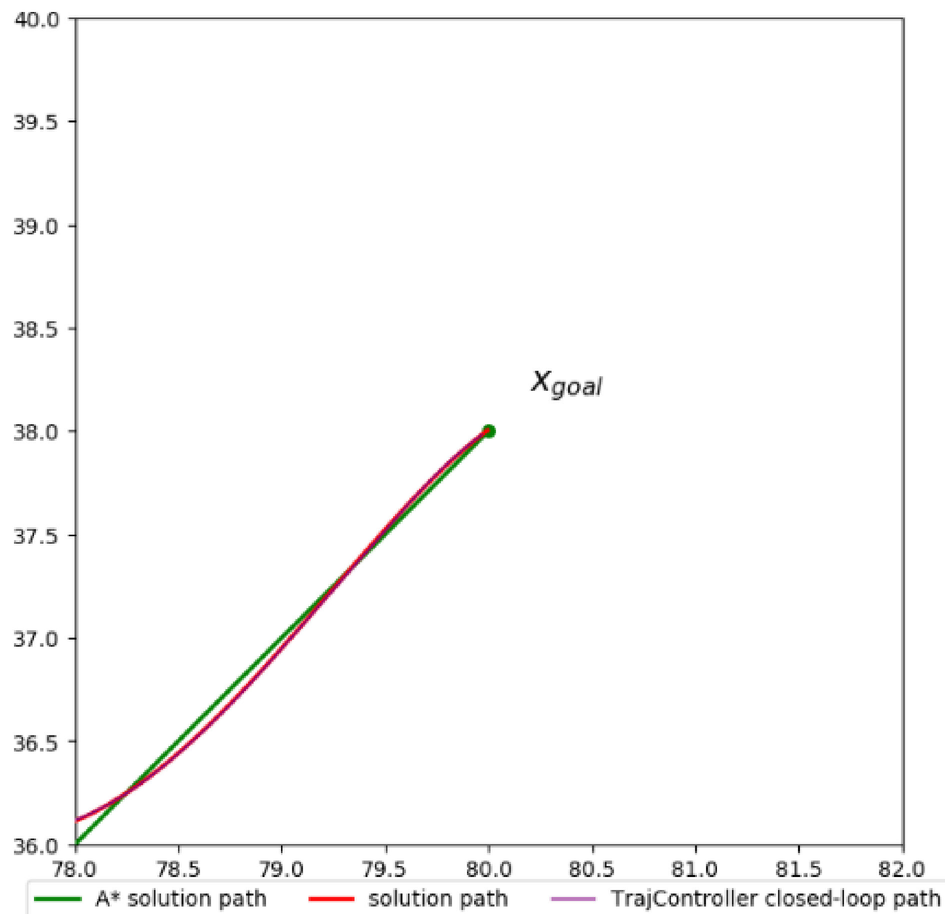
0.3 Switching from Trajectory Tracking to Pose Stabilization Control

0.3.1 Zoom in on final pose error

[ ]:
```
l_window = 4.

fig = plt.figure(figsize=[7,7])
astar.plot_path(fig.number, show_init_label = False)
plot_traj_smoothed(traj_smoothed)
plot_traj_cl(states_cl)
```

```
plt.legend(loc='upper center', bbox_to_anchor=(0.5, -0.03), fancybox=True,␣
 ↪ncol=3)
plt.axis([x_goal[0]-l_window/2, x_goal[0]+l_window/2, x_goal[1]-l_window/2,␣
 ↪x_goal[1]+l_window/2])
plt.show()
```



0.3.2 Pose stabilization control gains

Tune these as needed to improve final pose stabilization.

```
[ ]: k1 = 1.
k2 = 1.
k3 = 1.
```

0.3.3 Create pose controller and load goal pose

Note we use the last value of the smoothed trajectory as the goal heading θ

[ ]:
```
pose_controller = PoseController(k1, k2, k3, V_max, om_max)
pose_controller.load_goal(x_goal[0], x_goal[1], traj_smooth_scaled[-1,2])
```

0.3.4 Time before trajectory-tracking completion to switch to pose stabilization

Try changing this!

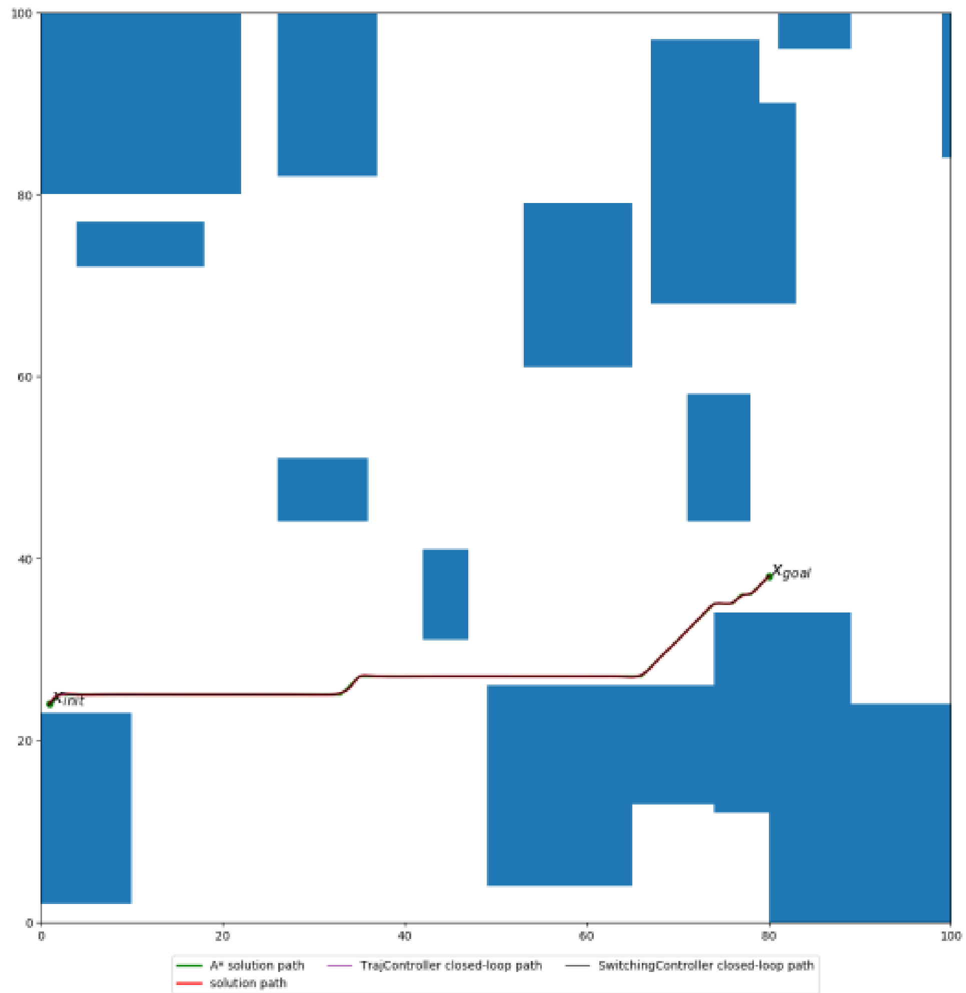
[ ]:
```
t_before_switch = 5.0
```

0.3.5 Create switching controller and compare performance

[ ]:
```
switching_controller = SwitchingController(traj_controller, pose_controller,␣
 ↪t_before_switch)

t_extend = 60.0 # Extra time to simulate after the end of the nominal trajectory
times_cl_extended = np.arange(0, tf_actual+t_extend, dt)
states_cl_sw, ctrl_cl_sw = simulate_car_dyn(s_0.x, s_0.y, s_0.th,␣
 ↪times_cl_extended, controller=switching_controller, noise_scale=noise_scale)

fig = plt.figure()
astar.plot_path(fig.number)
plot_traj_smoothed(traj_smoothed)
plot_traj_cl(states_cl)
def plot_traj_cl_sw(states_cl_sw):
    plt.plot(states_cl_sw[:,0], states_cl_sw[:,1], color="black", linewidth=1,␣
 ↪label="SwitchingController closed-loop path", zorder=10)
plot_traj_cl_sw(states_cl_sw)
plt.legend(loc='upper center', bbox_to_anchor=(0.5, -0.03), fancybox=True,␣
 ↪ncol=3)
plt.show()
```

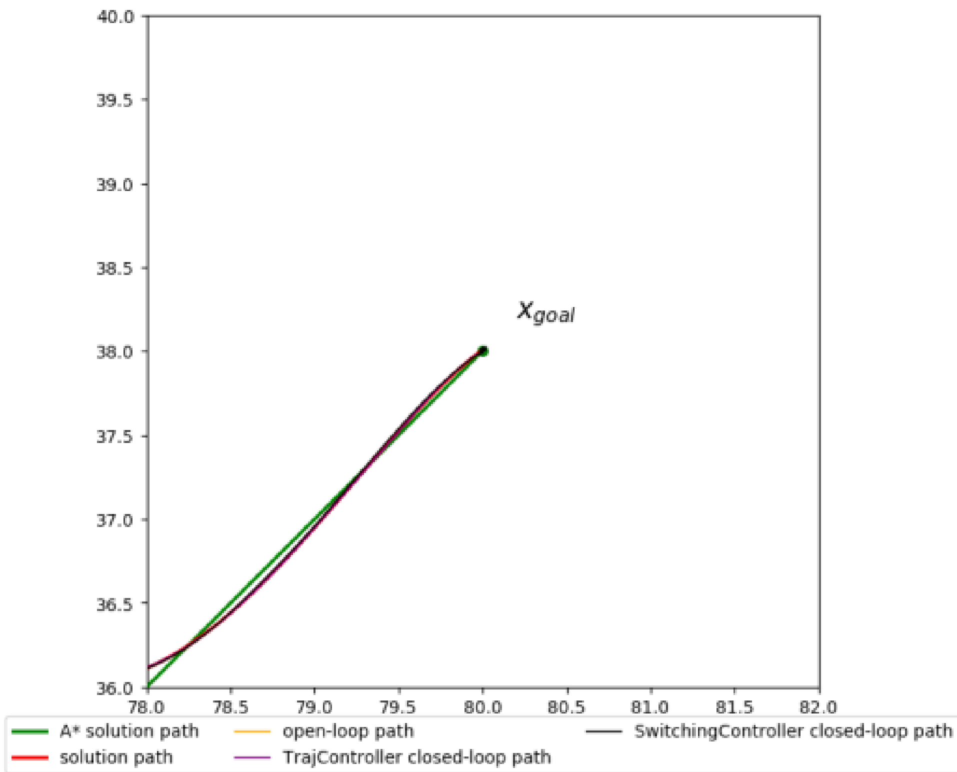


0.3.6 Zoom in on final pose

[ ]:
```
l_window = 4.

fig = plt.figure(figsize=[7,7])
astar.plot_path(fig.number, show_init_label = False)
plot_traj_smoothed(traj_smoothed)
plot_traj_ol(states_ol)
plot_traj_cl(states_cl)
plot_traj_cl_sw(states_cl_sw)
```

```
plt.legend(loc='upper center', bbox_to_anchor=(0.5, -0.03), fancybox=True,␣
↪ncol=3)
plt.axis([x_goal[0]-l_window/2, x_goal[0]+l_window/2, x_goal[1]-l_window/2,␣
↪x_goal[1]+l_window/2])
plt.show()
```



0.3.7 Plot final sequence of states

To see just how well we're able to arrive at the target point (and to assist in choosing values for the pose stabilization controller gains k_1, k_2, k_3), we plot the error in x and y for both the tracking controller and the switching controller at the end of the trajectory.

```
[ ]: T = len(times_cl) - int(t_before_switch/dt)
fig = plt.figure(figsize=[10,10])
plt.subplot(2,1,1)
plt.plot([times_cl_extended[T], times_cl_extended[-1]], [0,0], linestyle='--',␣
↪linewidth=1)
plt.plot(times_cl[T:], states_cl[T:,0] - x_goal[0], label='TrajController')
```

```
plt.plot(times_cl_extended[T:], states_cl_sw[T:,0] - x_goal[0],␣
 ↪label='SwitchingController')
plt.legend()
plt.ylabel("x error (m)")
plt.subplot(2,1,2)
plt.plot([times_cl_extended[T], times_cl_extended[-1]], [0,0], linestyle='--',␣
 ↪linewidth=1)
plt.plot(times_cl[T:], states_cl[T:,1] - x_goal[1], label='TrajController')
plt.plot(times_cl_extended[T:], states_cl_sw[T:,1] - x_goal[1],␣
 ↪label='SwitchingController')
plt.legend()
plt.ylabel("y error (m)")
```

```
[ ]: Text(0, 0.5, 'y error (m)')
```