AA 274A: Principles of Robot Autonomy I
Problem Set 2

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Problem 1: A* Motion Planning

(i) Implemented `is_free`, `distance`, `get_neighbors`, and `solve` in the `Astar` class.

(ii) `sim_astar.ipynb` starts on the next page.

A* Motion Planning

In [1]:
```
# The autoreload extension will automatically load in new code as you e
dit 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
```

Simple Environment

Workspace

(Try changing this and see what happens)

In [2]:
```
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)
```

Starting and final positions

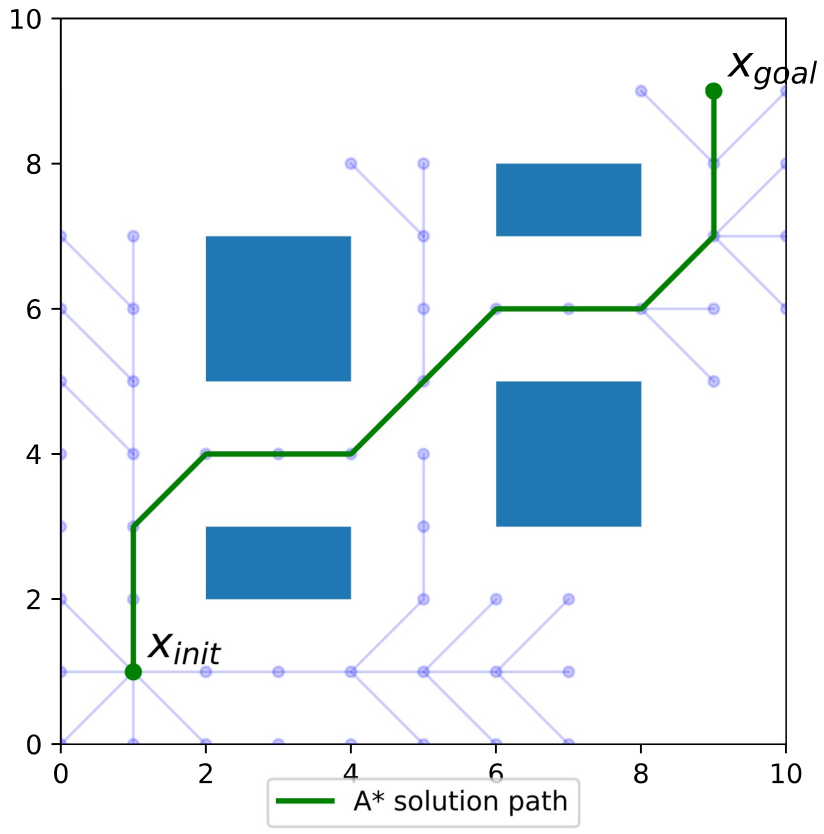
(Try changing these and see what happens)

In [3]:
```
x_init = (1, 1)
x_goal = (9, 9)
```

Run A* planning

```
In [4]: 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()
```

```
/home/parthiv/miniconda2/envs/aa274a/lib/python2.7/site-packages/matp
lotlib/cbook/deprecation.py:107: MatplotlibDeprecationWarning: Adding
an axes using the same arguments as a previous axes currently reuses
the earlier instance.  In a future version, a new instance will alway
s be created and returned.  Meanwhile, this warning can be suppresse
d, and the future behavior ensured, by passing a unique label to each
axes instance.
  warnings.warn(message, mplDeprecation, stacklevel=1)
```



Random Cluttered Environment

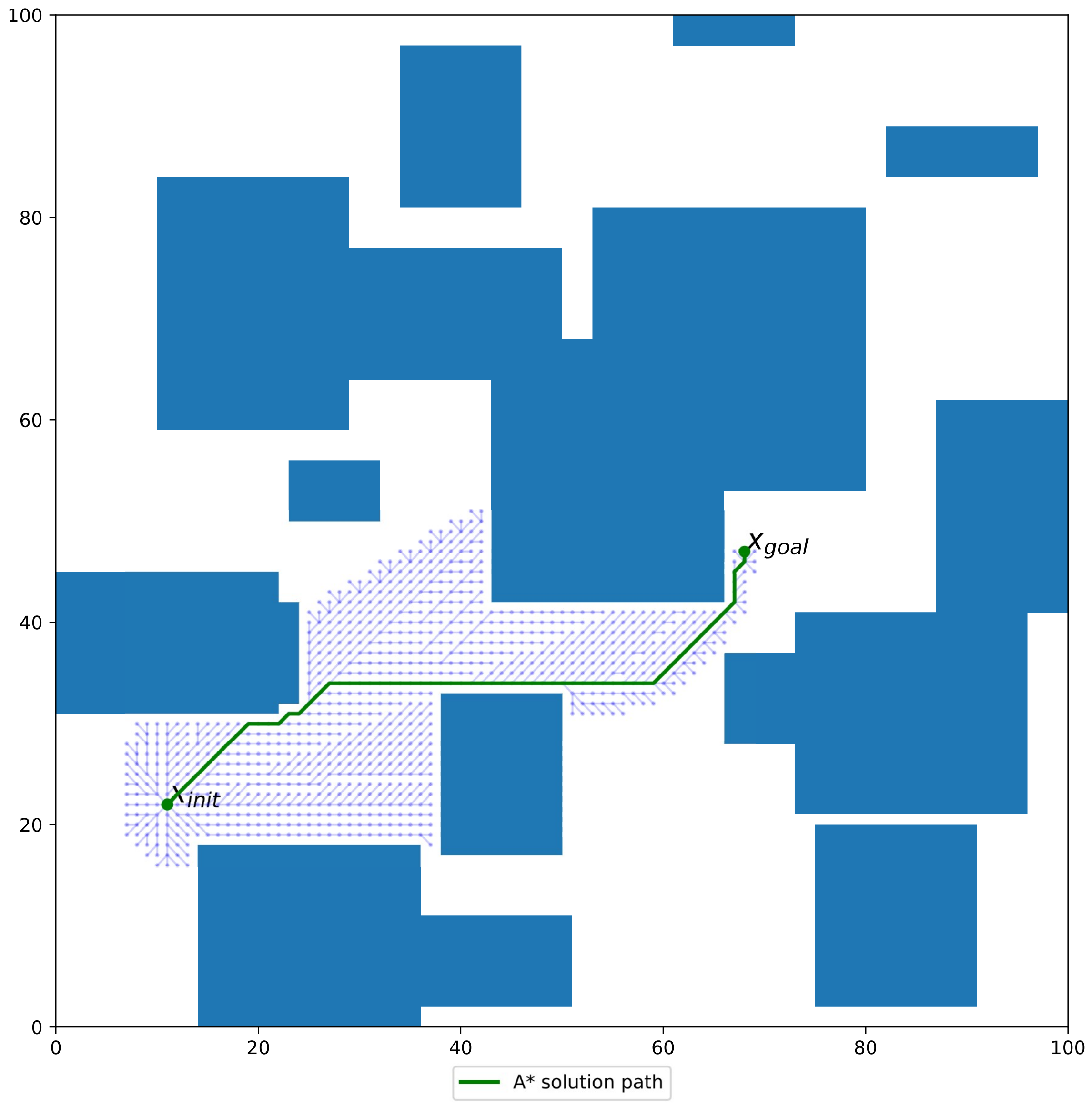
Generate workspace, start and goal positions

(Try changing these and see what happens)

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

occupancy, x_init, x_goal = generate_planning_problem(width, height, nu
m_obs, min_size, max_size)
```

Run A* planning

In [6]:
```
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)
```



In [ ]:

Problem 2: Rapidly-Exploring Random Trees (RRT)

(i) Implemented `RT.solve`, `GeometricRRT.findnearest`, and `GeometricRRT.steertowards` in `P2_rrt.py`.

(ii) `sim_rrt.ipynb` starts on the next page.

(iii) Implemented `DubinsRRT.findnearest` and `DubinsRRT.steertowards` in `P2_rrt.py`.

RRT Sampling-Based Motion Planning

In [1]:
```
# The autoreload extension will automatically load in new code as you e
dit 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
```

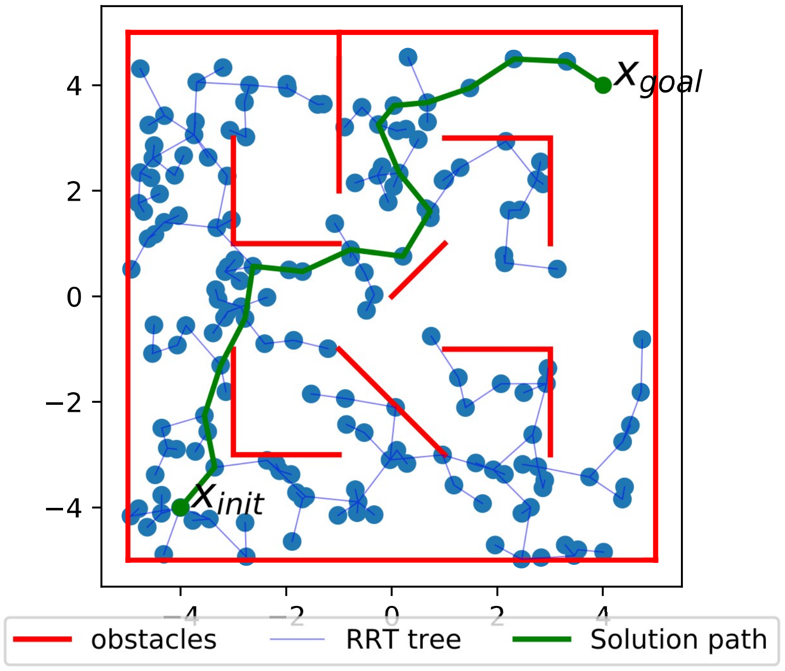
Set up workspace

In [2]:
```
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
```

Geometric Planning

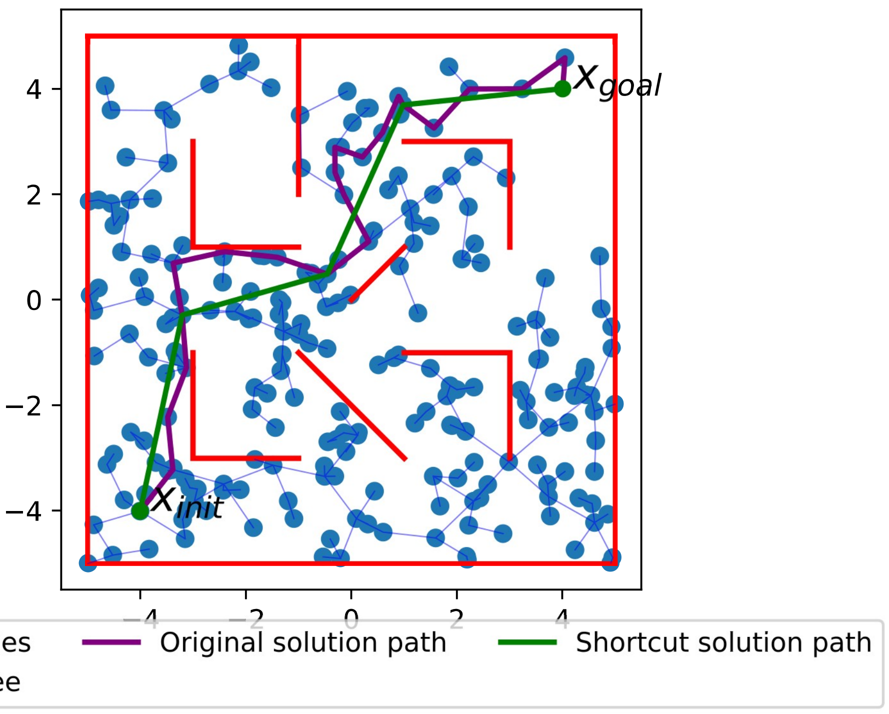
In [3]:
```
grrt = GeometricRRT([-5,-5], [5,5], x_init, x_goal, MAZE)
grrt.solve(1.0, 2000)
```

Out[3]:
```
True
```



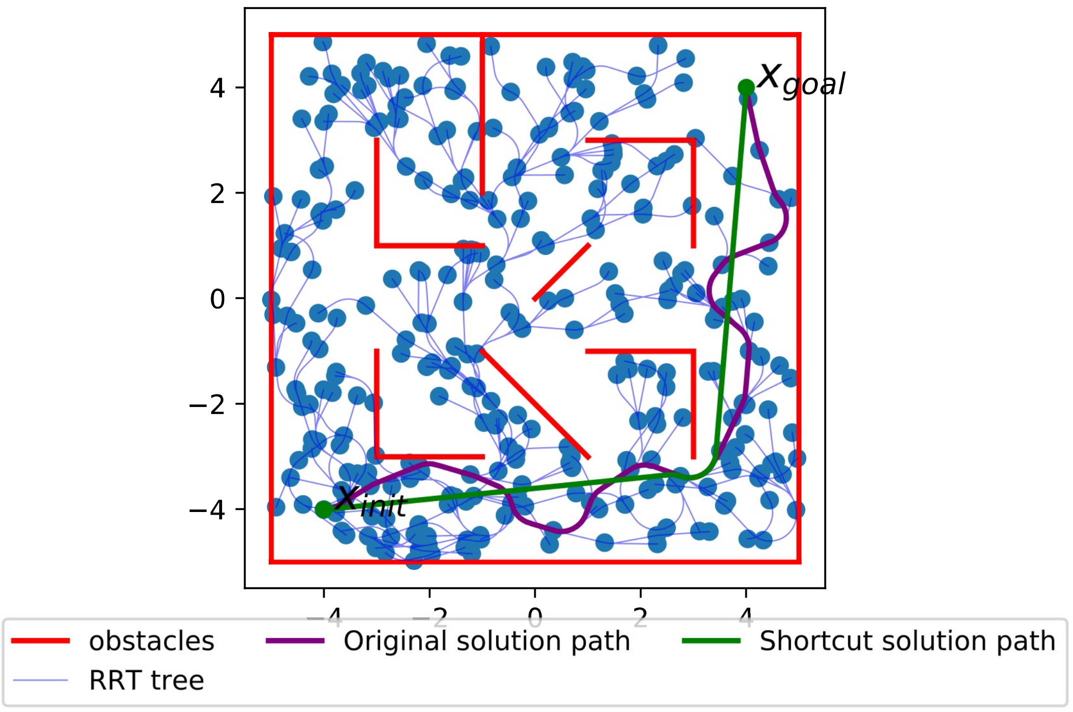
Adding shortcutting

```
In [4]: grrt.solve(1.0, 2000, shortcut=True)

Out[4]: True
```



Dubins Car Planning

```
In [5]: x_init = [-4,-4,0]
        x_goal = [4,4,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)

Out[5]: True
```



```
In [ ]:
```

Problem 3: Geometric Planning to Trajectories and Control

(i) Implemented `compute_smoothed_traj` in `P3_traj_planning.py`.

(ii) Implemented `modify_traj_with_limits`.

(iii) Implemented `SwitchingController.compute_control`.

(iv) `sim_traj_planning.ipynb` starts on the next page.

Geometric Planning to Trajectories and Control

In [1]:
```
# The autoreload extension will automatically load in new code as you e
dit 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 DetOccupancyGrid2D, AStar
from P2_rrt import *
from P3_traj_planning import compute_smoothed_traj, modify_traj_with_li
mits, SwitchingController
import scipy.interpolate
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

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

Generate workspace, start and goal positions

In [2]:
```
width = 100
height = 100
num_obs = 25
min_size = 5
max_size = 30

occupancy, x_init, x_goal = generate_planning_problem(width, height, nu
m_obs, min_size, max_size)
```

Solve A* planning problem

In [3]:
```
astar = AStar((0, 0), (width, height), x_init, x_goal, occupancy)
if not astar.solve():
    print "No path found"
```

Smooth Trajectory Generation

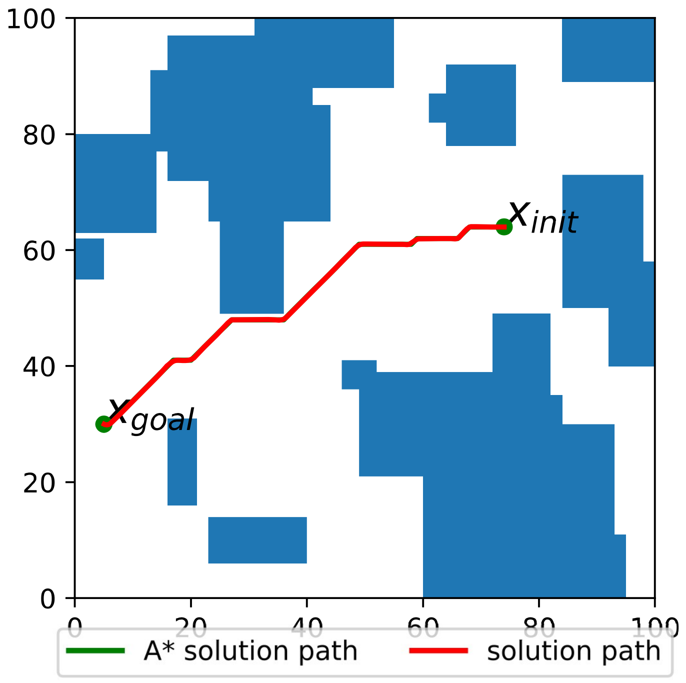
Trajectory parameters

(Try changing these and see what happens)

In [4]:
```
V_des = 0.3  # Nominal velocity
alpha = 0.1   # Smoothness parameter
dt = 0.05
```

Generate smoothed trajectory

In [5]:
```
traj_smoothed, t_smoothed = compute_smoothed_traj(astar.path, V_des, al
pha, 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", linew
idth=2, label="solution path", zorder=10)
plot_traj_smoothed(traj_smoothed)
plt.legend(loc='upper center', bbox_to_anchor=(0.5, -0.03), fancybox=Tr
ue, ncol=3)
plt.show()
```



Control-Feasible Trajectory Generation and Tracking

Robot control limits

In [6]:
```
V_max = 0.5 # max speed
om_max = 1 # max rotational speed
```

Tracking control gains

Tune these as needed to improve tracking performance.

In [7]:
```
kpx = 2
kpy = 2
kdx = 2
kdy = 2
```

Generate control-feasible trajectory

In [8]:
```
t_new, V_smooth_scaled, om_smooth_scaled, traj_smooth_scaled = modify_t
raj_with_limits(traj_smoothed, t_smoothed, V_max, om_max, dt)
```

Create trajectory controller and load trajectory

In [9]:
```
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)
```

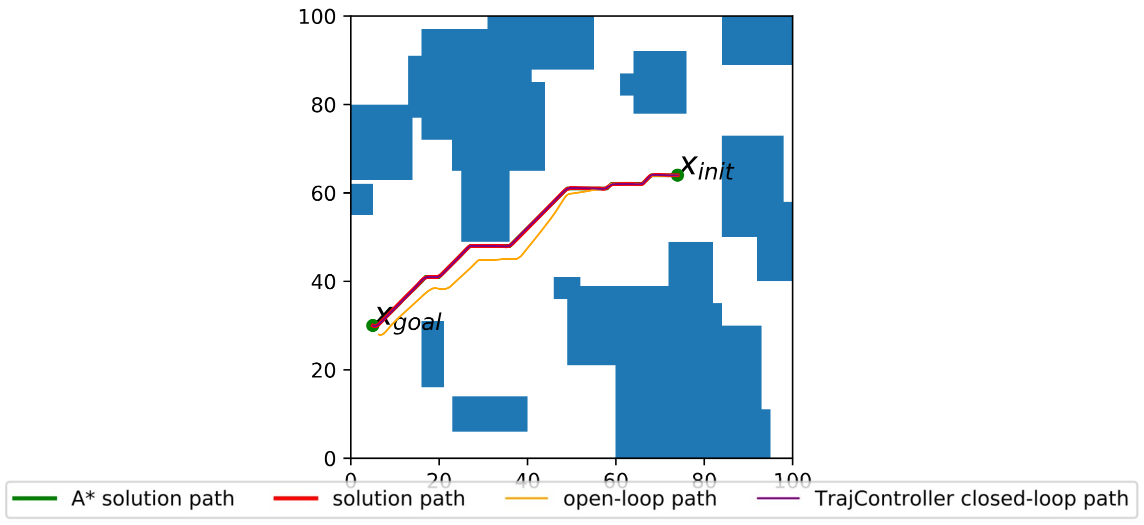
Set simulation input noise

(Try changing this and see what happens)

In [10]:
```
noise_scale = 0.05
```

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

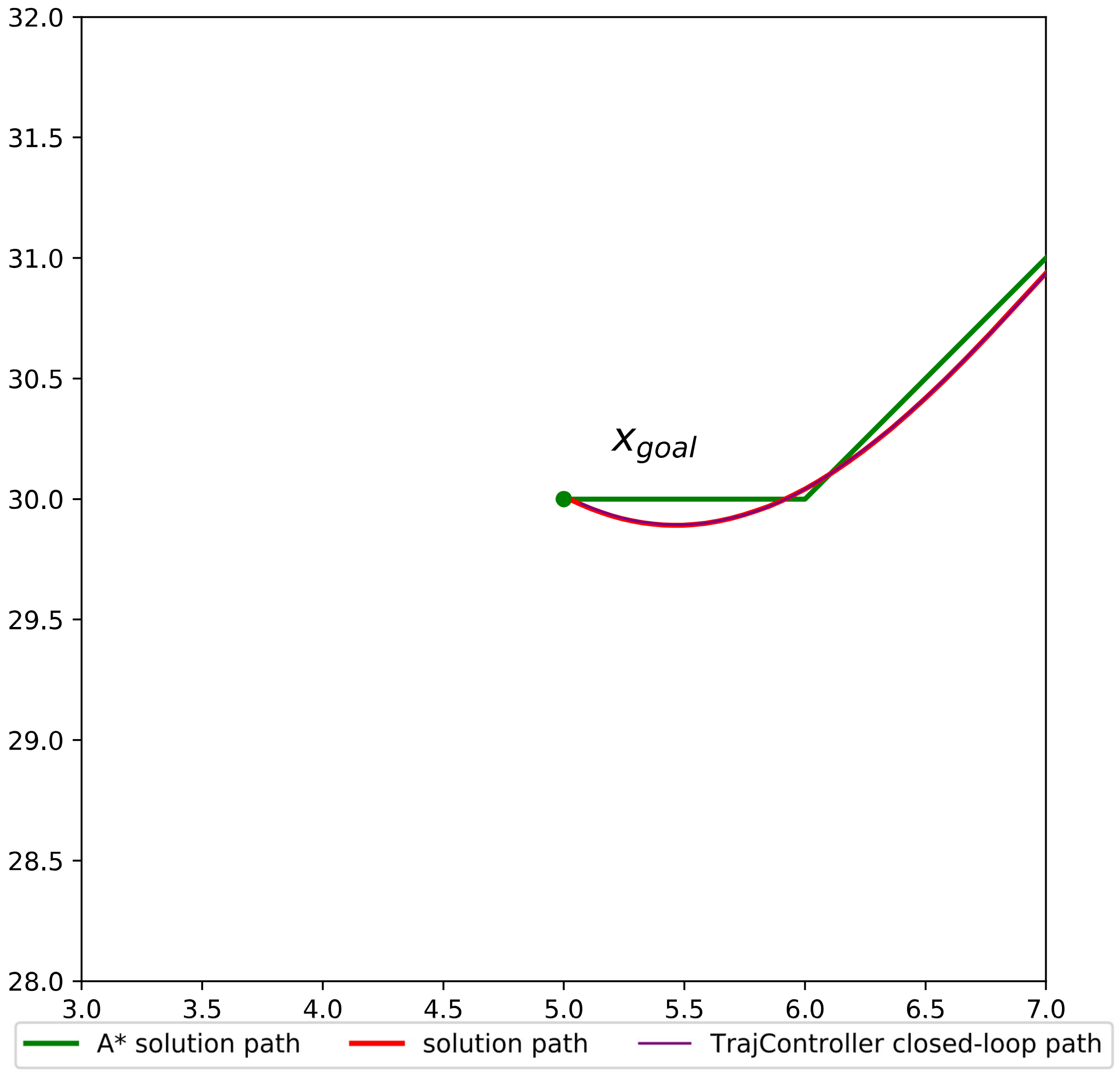
In [11]:
```
tf_actual = t_new[-1]
times_cl = np.arange(0, tf_actual, dt)
s_0 = State(x=x_init[0], y=x_init[1], V=V_max, th=traj_smooth_scaled[0,
2])
s_f = State(x=x_goal[0], y=x_goal[1], V=V_max, th=traj_smooth_scaled[-
1,2])

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, a
ctions=actions_ol, noise_scale=noise_scale)
states_cl, ctrl_cl = simulate_car_dyn(s_0.x, s_0.y, s_0.th, times_cl, c
ontroller=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=Tr
ue, ncol=4)
plt.show()
```



Switching from Trajectory Tracking to Pose Stabilization Control

Zoom in on final pose error

In [12]:
```
l_window = 4.

fig = plt.figure(figsize=[7,7])
astar.plot_path(fig.number)
plot_traj_smoothed(traj_smoothed)
plot_traj_cl(states_cl)
plt.legend(loc='upper center', bbox_to_anchor=(0.5, -0.03), fancybox=Tr
ue, ncol=3)
plt.axis([x_goal[0]-l_window/2, x_goal[0]+l_window/2, x_goal[1]-l_windo
w/2, x_goal[1]+l_window/2])
plt.show()
```



Pose stabilization control gains

Tune these as needed to improve final pose stabilization.

In [13]:
```
k1 = 1.
k2 = 1.
k3 = 1.
```

Create pose controller and load goal pose

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

In [14]:
```
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])
```

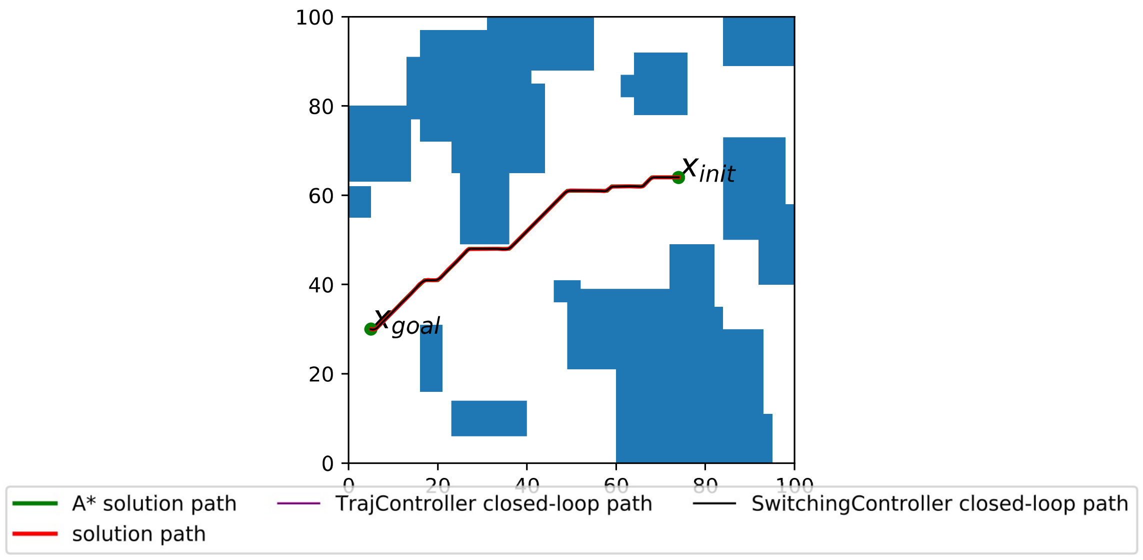
Time before trajectory-tracking completion to switch to pose stabilization

Try changing this!

In [15]:
```
t_before_switch = 5.0
```

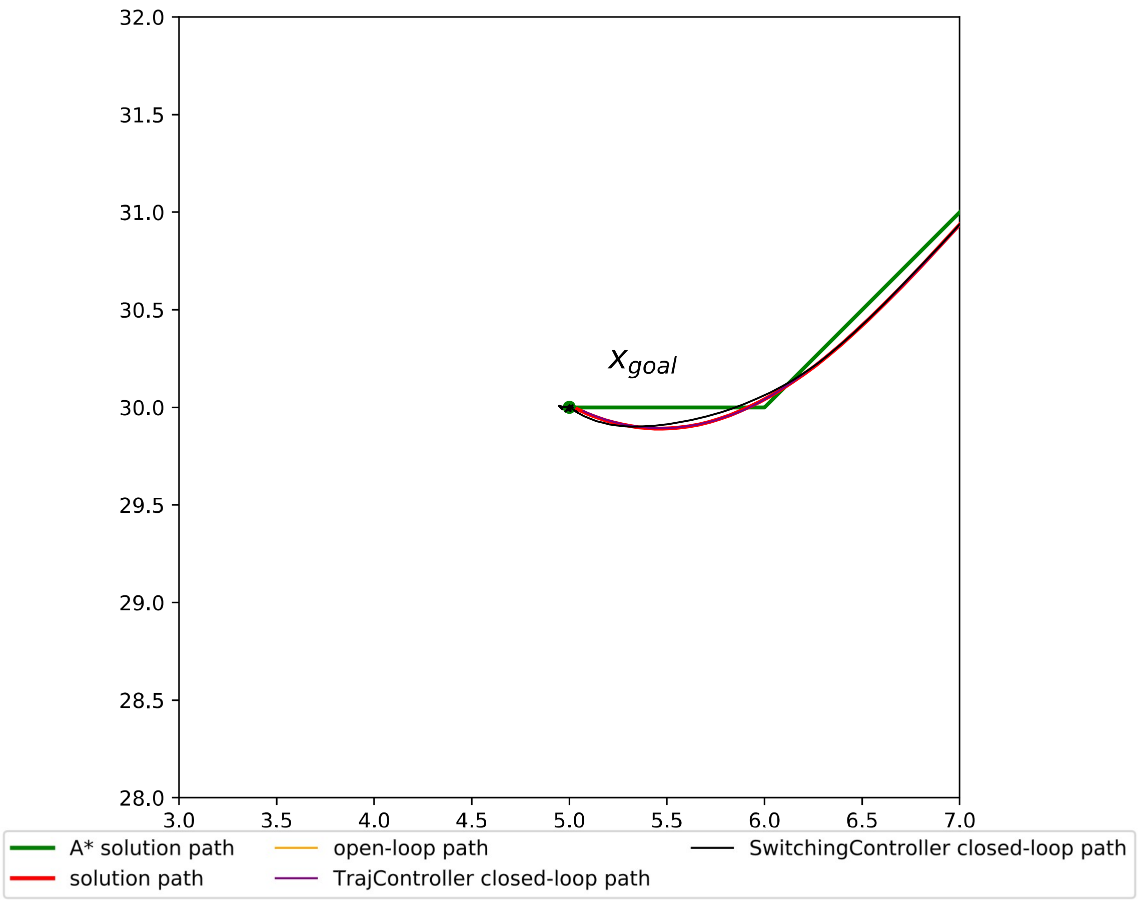
Create switching controller and compare performance

In [16]:
```
switching_controller = SwitchingController(traj_controller, pose_contro
ller, t_before_switch)

t_extend = 60.0 # Extra time to simulate after the end of the nominal t
rajectory
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", linew
idth=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=Tr
ue, ncol=3)
plt.show()
```



Zoom in on final pose

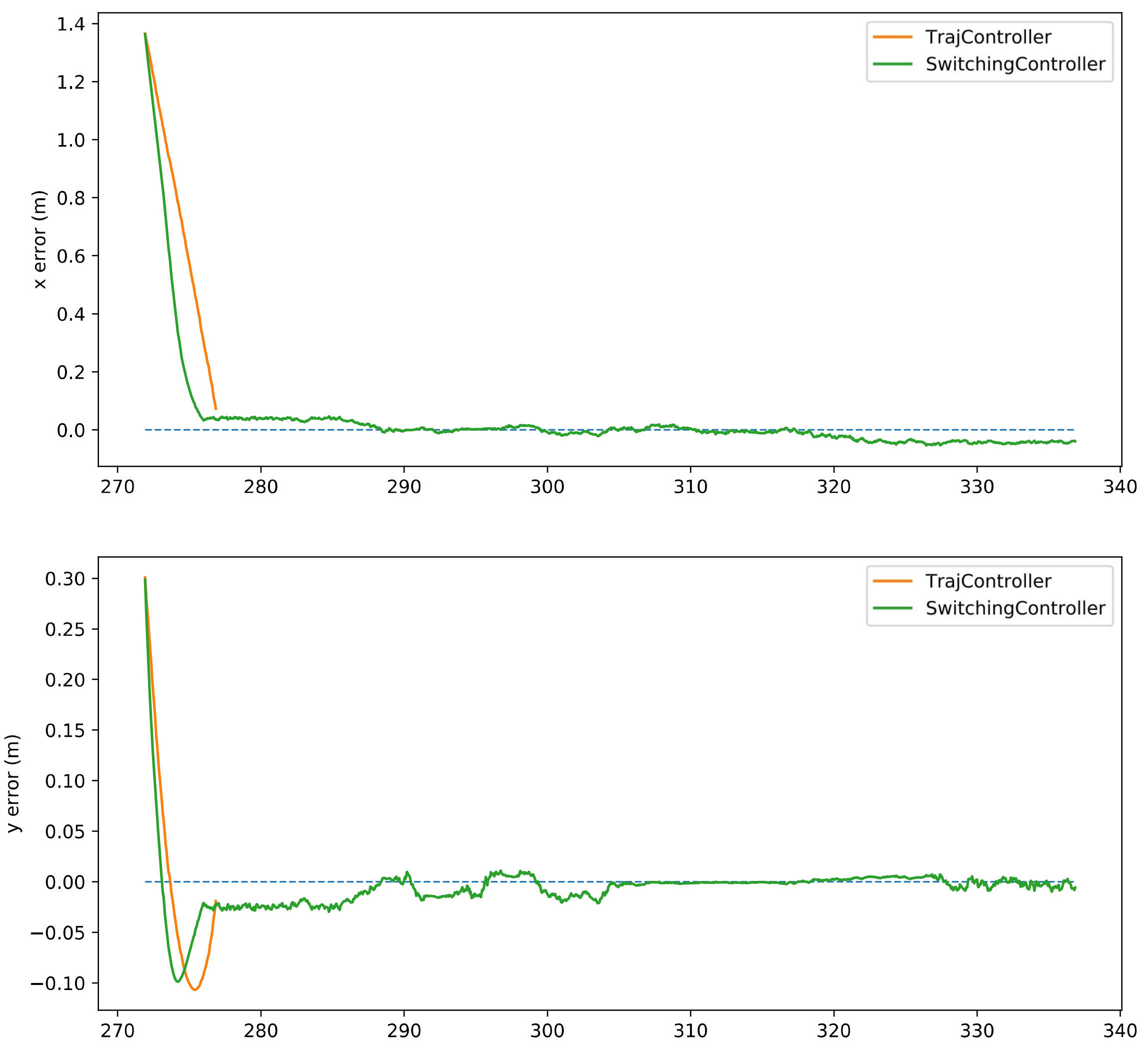
```
In [17]: l_window = 4.

fig = plt.figure(figsize=[7,7])
astar.plot_path(fig.number)
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()
```



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.

```
In [18]: 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], linestyl
         e='--', linewidth=1)
         plt.plot(times_cl[T:], states_cl[T:,0] - x_goal[0], label='TrajControll
         er')
         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], linestyl
         e='--', linewidth=1)
         plt.plot(times_cl[T:], states_cl[T:,1] - x_goal[1], label='TrajControll
         er')
         plt.plot(times_cl_extended[T:], states_cl_sw[T:,1] - x_goal[1], label='
         SwitchingController')
         plt.legend()
         plt.ylabel("y error (m)")

Out[18]: Text(0,0.5,'y error (m)')
```



In [ ]:

Extra Problem: Bi-Directional Sampling-based Motion Planning

(i) Implemented `RRTConnect.solve`, and the `GeometricRRTConnect` class functions `find_nearest_forward` and `steer_towards_forward` in `P4_bidirectional_rrt.py`.

(ii) Implemented the `DubinsRRTConnect` class functions `find_nearest_forward`, `find_nearest_backward` , `steer_towards_forward`, and `steer_towards_backward`.

(iii) `sim_traj_planning.ipynb` starts on the next page.

Bidirectional Sampling-Based Motion Planning

In [1]:
```
# The autoreload extension will automatically load in new code as you e
dit 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 *
from P4_bidirectional_rrt import *

plt.rcParams['figure.figsize'] = [7, 7] # Change default figure size
```

Set up workspace

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

Normal RRT

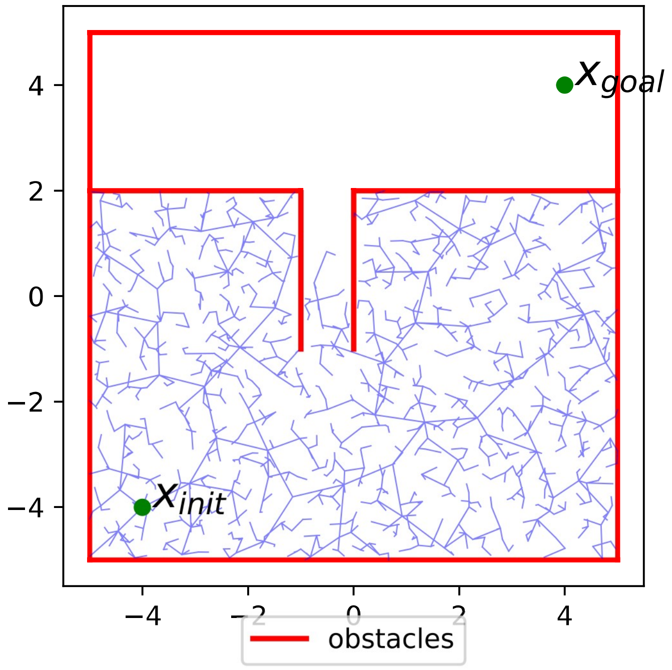
On this "bugtrap" problem, normal RRT often will fail to find a find a path.

Geometric planning

In [3]:
```
grrt = GeometricRRT([-5,-5], [5,5], [-4,-4], [4,4], MAZE)
grrt.solve(1.0, 2000)
```

```
Solution not found!
```

Out[3]:
```
False
```

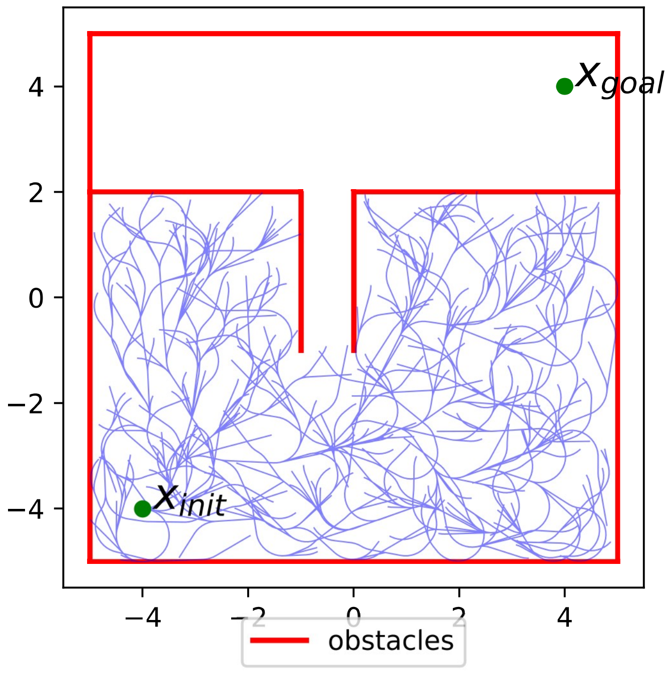


Dubins car planning

In [4]:
```
drrt = DubinsRRT([-5,-5,0], [5,5,2*np.pi], [-4,-4,0], [4,4,np.pi/2], MA
ZE, .5)
drrt.solve(1.0, 1000)
```

```
Solution not found!
```

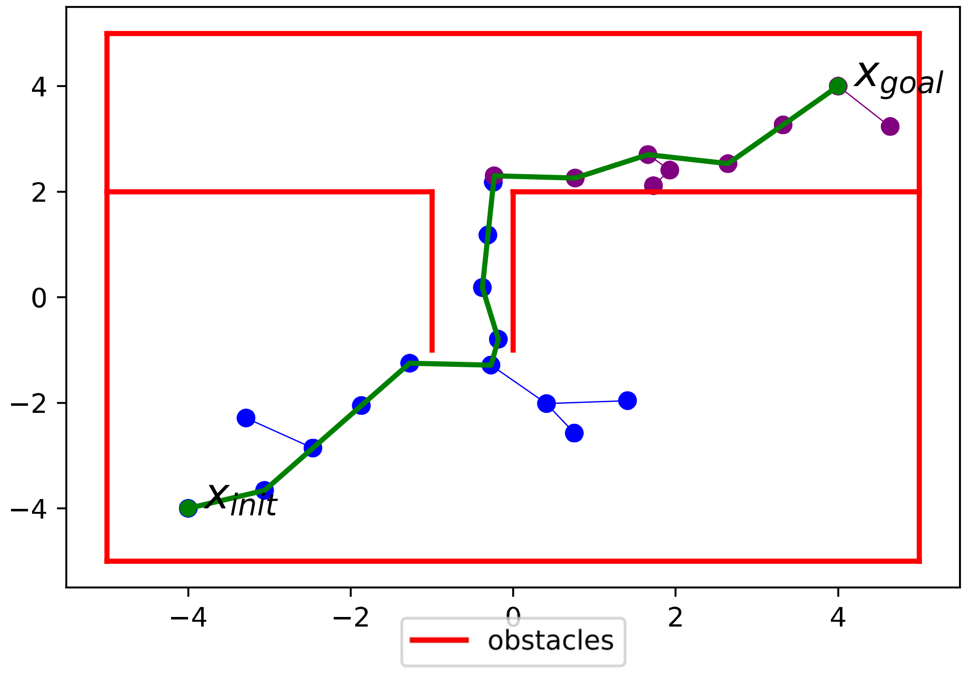
Out[4]:
```
False
```



RRTConnect

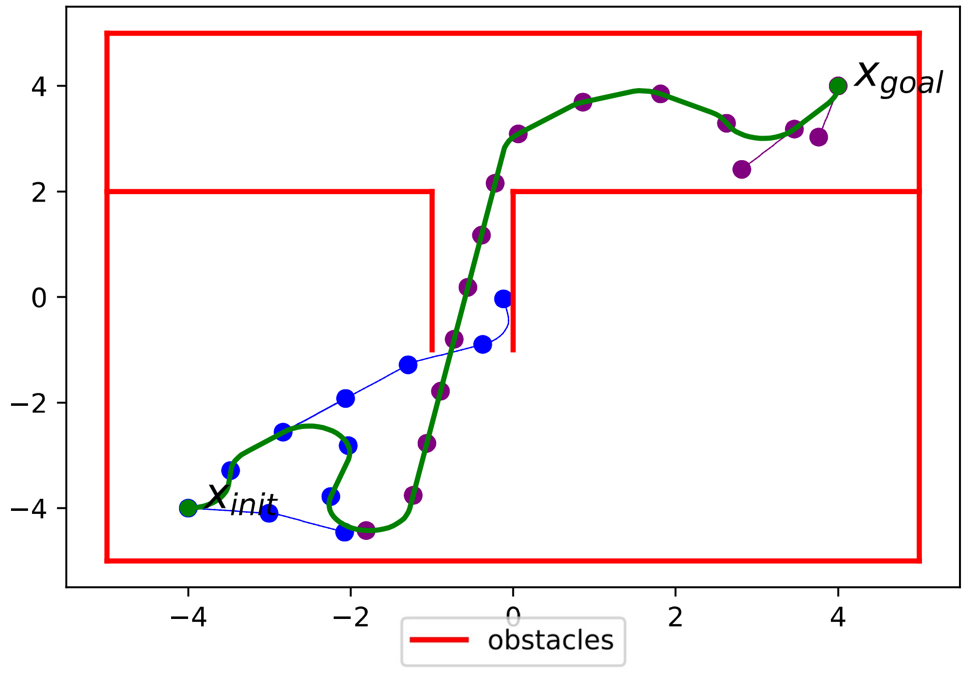
Geometric planning

In [5]:
```
grrt = GeometricRRTConnect([-5,-5], [5,5], [-4,-4], [4,4], MAZE)
grrt.solve(1.0, 2000)
```



Dubins car planning

In [6]:
```
drrt = DubinsRRTConnect([-5,-5,0], [5,5,2*np.pi], [-4,-4,0], [4,4,np.pi
/2], MAZE, .5)
drrt.solve(1.0, 1000)
```



```
In [ ]:
```