Ben Groelke
Final Project Report
ITCS – 8152

For my project, I implemented the vehicle motion planning algorithm CL-RRT. The kinematic single track car model was used as my robot model. Algorithm 1 was used to build the tree.

Algorithm 1 Expand_tree()

```
Take a sample s for input to controller.
Sort the nodes in the tree using heuristics.
for each node q in the tree, in the sorted order do
    Form a reference command to the controller, by
    connecting the controller input at q and the sample s.
    Use the reference command and propagate from q until
    vehicle stops. Obtain a trajectory x(t), t ∈ [t_1, t_2].
    Add intermediate nodes q_i on the propagated trajectory.
    if x(t) ∈ X_free(t), ∀t ∈ [t_1, t_2] then
        Add sample and intermediate nodes to tree. Break.
    else if all intermediate nodes are feasible then
        Add intermediate nodes to tree and mark them
        unsafe. Break.
    end if
end for
for each newly added node q do
    Form a reference command to the controller, by
    connecting the controller input at q and the goal
    location.
    Use the reference command and propagate to obtain
    trajectory x(t), t ∈ [t_3, t_4].
    if x(t) ∈ X_free(t), ∀t ∈ [t_3, t_4] then
        Add the goal node to tree.
        Set cost of the propagated trajectory as an upper
        bound C_UB of cost-to-go at q.
    end if
end for
```

Figure 1. Source: https://ieeexplore.ieee.org/document/5175292/

Samples $\boldsymbol{s}$ generated using a reference position, (x_0, y_0) and heading, θ_0. where η_r and η_θ are random variables with standard Gaussian distributions.

$$\begin{bmatrix} s_x \\ s_y \end{bmatrix} = \begin{bmatrix} x_0 \\ y_0 \end{bmatrix} + r \begin{bmatrix} \cos(\theta) \\ \sin(\theta) \end{bmatrix} \text{ with } \begin{cases} r = \sigma_r |n_r| + r_0 \\ \theta = \sigma_\theta n_\theta + \theta_0 \end{cases}$$

After a sample was generated, nodes were sorted via Dubins distance in ascending order. Connections between the nodes and the sample were then attempted in the sorted order. If a connection was successful, three nodes were added to the tree; one node was the sample and two nodes along the trajectory from the start node to the sample were added to the tree. Each node in the tree contained the states $\boldsymbol{x}$ and the input, $\boldsymbol{r}$. After a successful connection between a node and sample was made, connections were attempted between the added nodes and the goal configuration, which was essentially an x and y position. A successful connection was one that was collision free. Collision was detected by representing the vehicle as a rectangle, and representing the environment with 20cmX20cm cells, each belonging to either obstacles or free space. If the rectangle that represented the vehicle intersected a cell that was an obstacle, it was considered that a collision had occurred. The commanded velocity was determined by a function of estimated distance to go, implementing this was one of the more challenging aspects of this project. Steering angle geometries was another challenging aspect. In addition to finding complete paths to the goal configuration, costs-to-go were calculated for each tail of parent nodes. These costs-to-go were representative if distance, so the smallest cost-to-go corresponds to the shortest distance. Shortest control input ($\boldsymbol{r}$) paths are shown in the results as a bold black line. Samples are indicated with stars, and state trajectories are indicated with circles. In the results shown nodes added earlier to the tree are represented by cooler colors. Here are some preliminary results:

U obstacle:

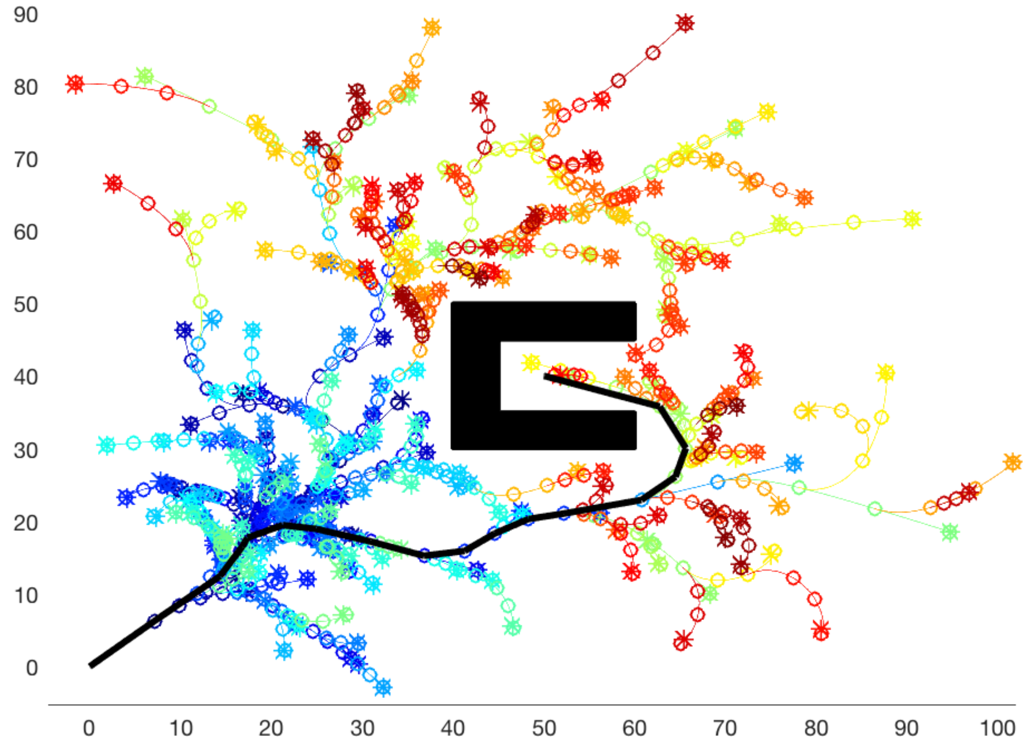

Figure 2. 300 samples were taken, σ_r= 20, σ_θ=π/10, r_0=20 for the first 150 samples and r_0 = 40 for the second 150 samples. Goal configuration is at (50,40);

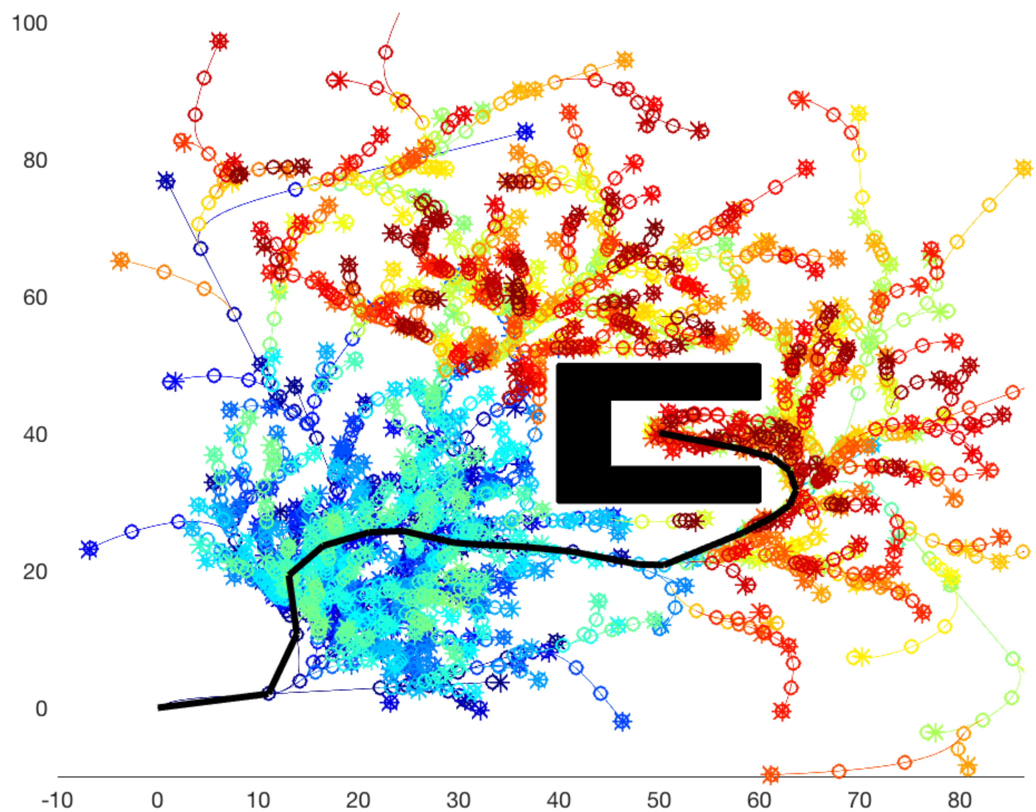

Figure 3 1000 samples were taken, σ_r= 20, σ_θ=π/10, r_0=20 for the first 500 samples and r_0 = 40 for the second 500 samples. Goal configuration is at (50,40);

Maze:

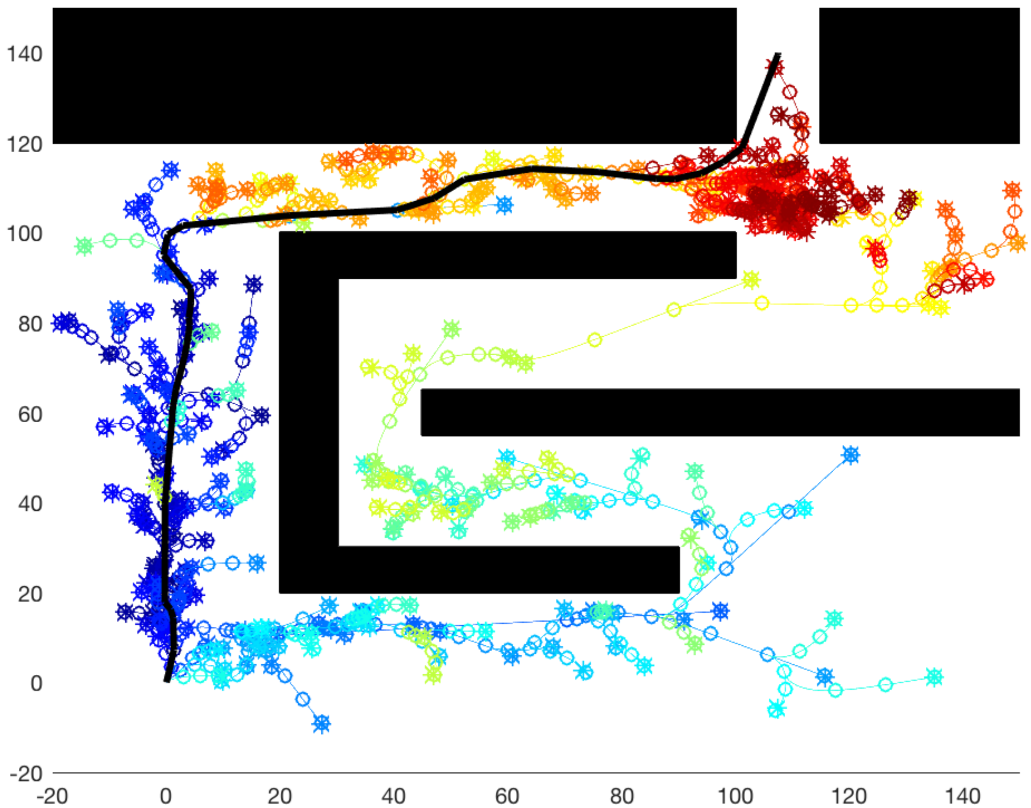

Figure 4. In this simulation 5 regions were sampled to emphasize exploration. 500 samples were taken in all. Goal configuration is at (107.5, 140)

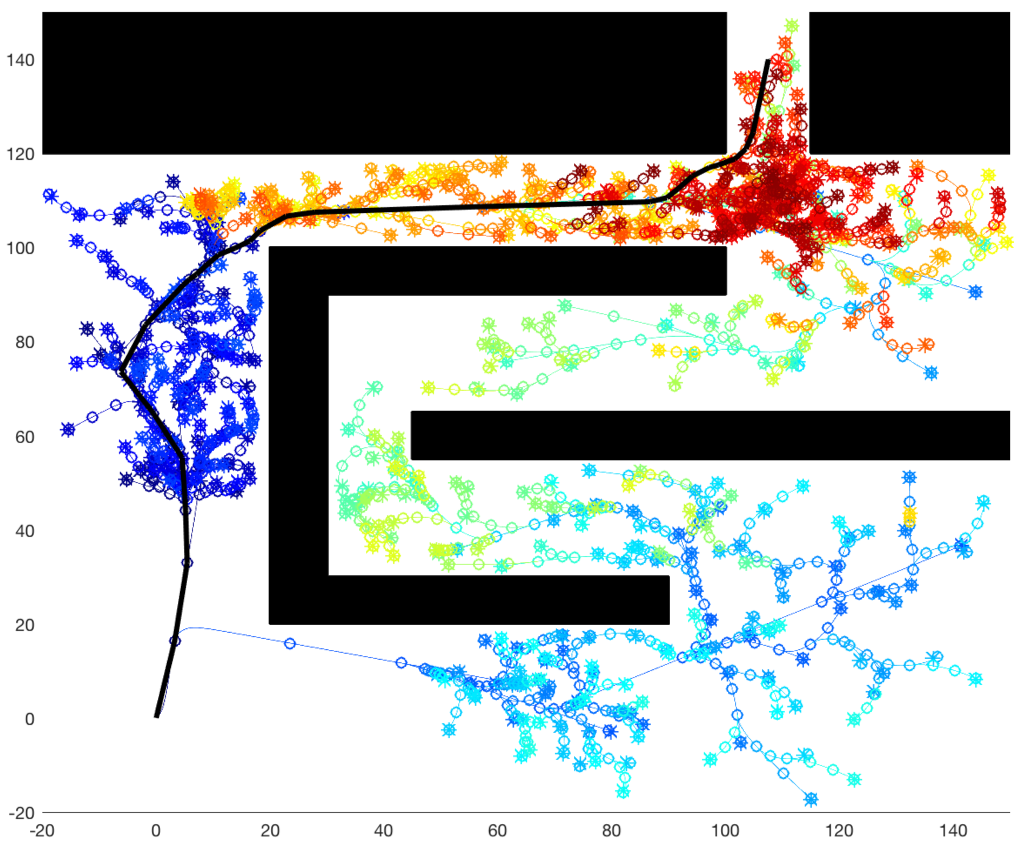

Figure 5. In this simulation, 5 regions were sampled to emphasize exploration. 1000 samples were taken in all. Even still there is a lack of nodes around point (107.5,140)

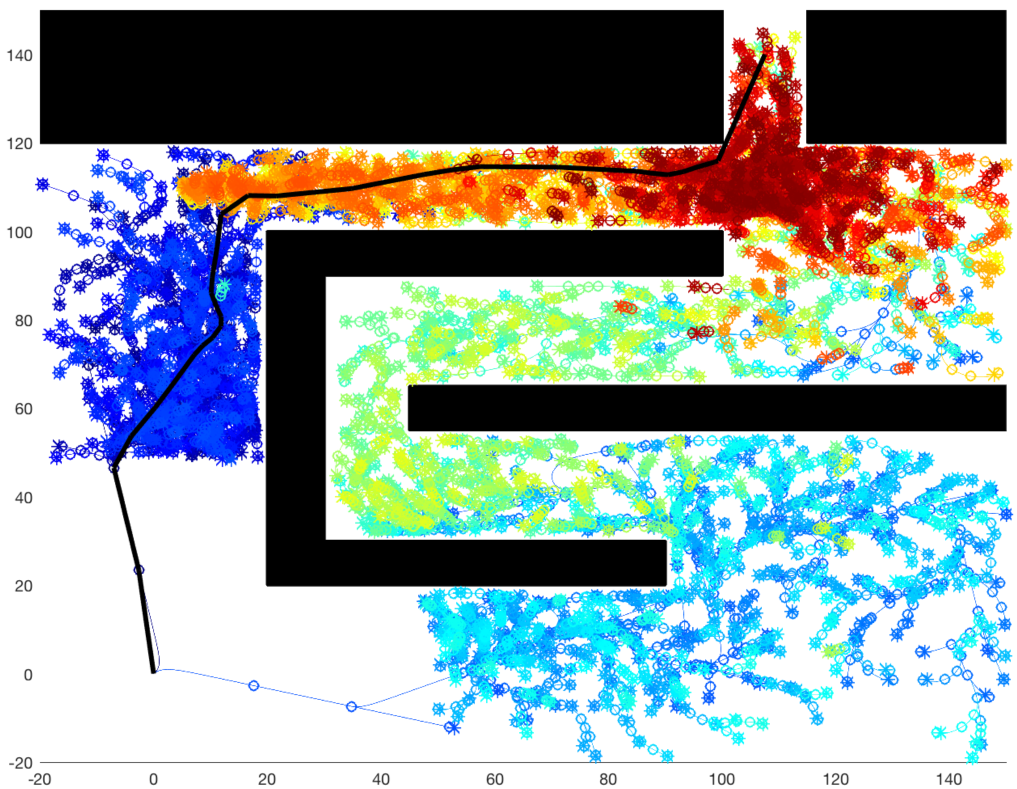

Figure 6 In this simulation, 5 regions were sampled to emphasize exploration. 5000 samples were taken in all. Even still there is a lack of nodes around point (107.5,140)