1. You want to find a driving route that minimizes the number of turns between two locations in Boulder.

   (a) Would you rather employ a sampling-based continuous algorithm or a discrete algorithm such as Dijkstra or A* for doing this and why?

   I would employ a discrete algorithm, as you could use a cost function that weights making a turn very heavily, and weights going straight very lightly, then mixes in distance.

   (b) Provide a possible cost function that encodes both path length l and number of turns t between two states that heavily prioritizes not making turns if possible. You may assume that you are given l and t for any given pair of states (e.g., through the functions distance(s_1, s_2) and num_turns(s_1, s_2) respectively).

   $c = l + t^3$
   This cost function heavily prioritizes not making turns if at all possible.

2. Assume that points are sampled uniformly at random in a randomized planning algorithm. Calculate the limiting behavior of the following ratio as the number of points sampled goes to infinity: (number of unique points in tree)/(number of points sampled). Assume the total area A_{total} (including free space and obstacles) and the area of free space A_{free} (no obstacles) within are known.

   $\frac{A_{free}}{A_{total}}$, based on only free space samples being inserted into the tree.

3. Assuming a k-d-tree (e.g., quadtree, octree, etc.) is used as a nearest-neighbor data structure to store a run of RRT's output graph and points are sampled uniformly at random, calculate the expected run-time of inserting a point into a tree of size N. Use "big-O" notation, e.g. O(N)

   O(logN) (techincally $\log_k$N, but the the two are asymptotically equivalent)

4. Why does the bandwidth of an Ultrasound-based distance sensor decrease significantly when increasing its dynamic range, but that of a laser range scanner does not for typical operation? [Hint: what is the limiting factor in an ultrasonic sensor? What about a laser scanner?]

   Ultrasound uses sound, laser uses light, light travels much faster, so laser isn't affected nearly as much by increasing distance.

5. You are designing an autonomous electric car to transport goods on campus. As you are worried about cost, you are thinking about whether to use a laser scanner or an ultra-sound sensor for detecting obstacles. As you drive rather slow, you are required to sense up to 30 meters. The laser scanner you are considering can sense up to this range and has a bandwidth of 5Hz.

   (a) Calculate the time it takes until you hear back from the ultrasonic sensor when detecting an obstacle 30m away. Assume that the robot is not moving at this point. Use c = 300 m/s for the speed of sound.

   (60 m) / (300 m/s) = .2 seconds

   (b) Calculate the time it takes until you get a reading from the laser scanner. [Hint: You do not need the speed of light to answer this question]

   5 Hz = 5 readings/second = .2 seconds/reading

6. A GPS sensor provides position estimates within a circle of approximately 3m in diameter. Every now and then the satellites on the horizon change and the center of this circle moves elsewhere, approximately staying within a 30m radius of the true location of the receiver.

   (a) Given the error data above, which value corresponds to accuracy and which to precision?

   30m is accuracy, 3m is precision.

   (b) The sensor provides 18000 readings per hour. What is its bandwidth?

   (18000 readings/hour) / (3600 seconds/hour) = 5 readings/second = 5 Hz