Assignment: In this project, you will build a state estimation module that estimates
the location of the car (so called ‘\textit{localizer}’) and build a map of road
boundary that will be extracted from image data (‘\textit{map building}’). That is, this project have two parts as following.

In the first step, given the current location, the current velocity of car and
the detected GPS location, \textbf{estimate the location of the car}. Next, given
the location of car and image data, extract the two border lines that
confine the drivable area (forget about the center line, focus only on the
road boundary). \textbf{Accumulating the extracted drivable area (local
map), build a global map of entire road that includes the driv-
able area in our data.}

The GPS data and a movie file can be downloaded from
http://reason.cs.uiuc.edu/cs440/urbanchallenge/project2/gps.dat
http://reason.cs.uiuc.edu/cs440/urbanchallenge/project2/project2_capture.avi

Localization: Motivation: the GPS is quite accurate and useful. Normally one location
on earth may get signals from 7 to 8 GPS satellite. (Theoretically 3
GPS signals are enough to locate a position) However, the accuracy is not
enough to drive a car. In Figure 1 the GPS failed under the big trees
and near the building. (The locations that have no tracking point in the
trajectory). Thus, we need to build a localization module that estimates
the location with/without GPS signals.

Theory: To estimate location of car($L$), we need two dynamic bayesian
models. The first one is the motion model: given the location($L_t$) and
velocity($v_t$) of car at time $t$, the model estimates the location of the
car($L'_t$). The second one is the sensor model: given the current location($L'_t$)
and sensor observation($O_t$), the model corrects the location($L_{t+1}$) of the
Figure 1: GPS Tracking data
car based on the observation (Here GPS data).

The ‘motion model’ is $P(L'_t|L_t, v_t)$. It is straight forward. Assume that the error of this model has gaussian distribution. Here we assume that the current velocity of the car is proportional to the difference of the previous estimated locations. That is, the velocity is approximately $v_t = (L_t - L_{t-n})/nm/sec$ (Actually, our inertial sensor currently has problem. If we can get the velocity we’ll give you).

Please model the concrete ‘motion model’ for your localizer.

The ‘sensor model’ is $P(L_{t+1}|L'_t, O_t)$. To estimate the location, we use Bayesian Rule. Suppose that we have an error model of observation $P(L_{t+1}|O_t)$.

$$P(L_{t+1}|L'_t, O_t) = \frac{P(O_t|L_{t+1}) \cdot P(L_{t+1}|L'_t)}{P(O_t|L'_t)}$$

We do not need to care about $P(O_t|L'_t)$, because $O_t$ is already occurred. Assume that we know that $P(O_t|L_{t+1})$ (error model of the sensor) is know. $P(L_{t+1}|L'_t)$ is the error model of the current location. You need to design the error models and to assign parameters.

In general, the error increase without the GPS signals.

Filters: In implementation, you may choose between Kalman Filter and Particle Filter (Please refer the Russell & Norvig book). Otherwise you may design your custom filter (Dynamic Bayesian Network). However, you need to compare the advantage and disadvantage of two filters (and your custom filter) in your report.

Map Building: Motivation: In our daily driving, we need to drive slowly and pay attention to find location, if we have no global map. So does the autonomous vehicle. Without the global map, the vehicle should pay attention to distinguish drivable area and localize the area. With the learned global map, we can speed up our vehicle (The fastest team win the DARPA challenge) and increase the accuracy of the localizer.

Theory: Given the image we can extracted the road boundary. Let the two boundaries, which are close to the current location, $BL_t, BR_t$ (left and right) at time t. We need to build the global road boundary $B_{map}$. The problem is following

$$B_{map} = \arg\max_{map} P(map|BL_1, BR_1, ...BL_n, BR_n)$$
Although there are many ways to choose the optimal map \( B_m \), simplify the procedure with good hypothesis. For example, you may hypothesize the road is straight and find the lines with hough transform. However, you may need to adjust the road boundaries with angular translation, because the orientation of GPS and the head of camera may have error.

**Evaluation:** By the due date, please submit your report and result (map and estimated locations) through compass
http://compass.cs.uiuc.edu/

The report should includes your methods, algorithms and results.

The the output file of estimated locations is following format
"time_step, gps x, gps y, gps angle, est. x, est. y, est. angle, area of 90% confidence of estimated location"

It is optional to present the estimated location in GUI, although we recommend to do.

The output map should include all the area the vehicle has visited with the 1m by 1m cell. **If the cells are drivable area within boundary, mark the area with ‘0’. Otherwise mark the are with ‘1’.

**When evaluating your implementation, we will remove some parts of GPS signals to test robustness. In addition, we’ll run your code against the another test set.**

**Reference:** You may use whatever algorithms you want to use. In addition, you may use the Matlab modules that are built by other universities or research groups (not including the other groups in CS 440), if you correctly state that you use their code.

**Please present your result images at your team web page.** (I want to you make your own web page instead of web page files. That’s the prof Eyal wants to do. If you have no account for web page please let me know)

If you have any question, please e-mail to TAs.