Module 1: The Requirements for Autonomy
Lesson 1: Taxonomy of Driving

Driving task:
1.perceiving the environment
2.planning how to reach from point A to B
3.controlling the vehicle

Operational Design Domain (ODD)
The ODD constitutes the operating conditions under which a given system is designed to function.
例えば、environmental, time of day, roadway and other characteristics under which the car will perform reliably.
Clearly defining the operating conditions for which a self-driving car is designed, is crucial to ensuring the safety of the system. So the ODD needs to be planned out carefully in advance.

How to classify driving system automation?
Driver attention requirements
Driver action requirements

What makes up a driving task?
Lateral control - steering
Longitudinal control - braking, accelerating
Object and Event Detection and Response (OEDR): detection, reaction（immediate responseが含まれる、planningとは別）
Planning - long term, short term。例えばlane change, intersection crossing
Miscellaneous (signaling with indicators)

Autonomous Capabilities
OEDR : Automatic emergency response, Driver supervision
Complete vs Restricted ODD

Level 1 - Driving Assistance
either Longitudinal Control or Lateral Control
Examples: Adaptive cruise control (can control speed, driver has to steer), Lane Keeping Assistance

Level 2 - Partial Driving Automation + Both
Examples: GM Super Cruise, Nissan ProPilot Assist (driver monitoring必要)

Level 3 - Conditional Driving Automation + OEDR
in the case of failure the control must be taken up by the driver.
This is a controversial level of automation as it is not always possible for an autonomy system to know when it is experiencing a failure.
Example: Audi A8 Sedan

Level 4 - High Driving Automation + Fallback
Handles emergencies autonomously, driver can entirely focus on other tasks.
Level 4 system can handle emergencies on their own but may still ask drivers to take over to avoid pulling over（路肩に寄せる） to the side of the road unnecessarily.
(fall 2018) only Waymo!

Level 5 - High Driving Automation + Unlimited ODD

Limitations of this taxonomy

ODD and safety record are more important.
It is possible for two car models to claim level four autonomy but have very different capabilities in ODDs.

Lesson 2: Requirements for Perception

Perceptionのtwo things: identification, understanding motion

Goals for perception: static objects, dynamic objects, ego localization.
The data used for ego motion estimation comes from GPS, IMU and odometer.

Challenges to perception
- robust detection and segmentation
- sensor uncertainty
- occlusion, reflection
- illumination, lens flare（レンズフレア）
- weather, precipitation

Lesson 3: Driving Decisions and Actions

long term, short term, immediate planning

Rule Based Planning (=Reactive Planning)
Predictive Planning: predictive planning is the predominant method for self-driving cars, as it greatly expands the scenarios a vehicle can handle safely.

fluent in C++ and Python
machine learning experience
be a proud software engineer about the quality of the code that you're writing and you will do well.

Module 2: Self-Driving Hardware and Software Architectures

Lesson 1: Sensors and Computing Hardware

Sensors: device that measures or detects a property of the environment, or changes to a property.
Categorization:
- exteroceptive: surroundings (Camera)
- proprioceptive: internal

Exteroceptive Sensors

Camera: passive, light-collecting sensor
カメラの3つcomparison metrics:
- Resolution : the number of pixels that create the image
- Field of View: the horizontal and vertical angular extent that is visible to the camera, and can be varied through lens selection and zoom.
- Dynamic range: the difference between the darkest and the lightest tones in an image. High dynamic range is critical for self-driving vehicles due to the highly variable lighting conditions encountered while driving especially at night.
  - A tone is one of the lighter, darker, or brighter shades of the same color
  - A shade of a particular color is one of its different forms. For example, emerald green and olive green are shades of green.

Trade-off between resolution and FOV:

Wider field of view permits a larger viewing region in the environment. But fewer pixels that absorb light from one particular object.
Stereo Camera
The combination of two cameras with overlapping fields of view and aligned image planes.
depth estimation from synchronized image pairs.
Pixel values from image can be matched to the other image producing a disparity map of the scene.
This disparity can then be used to estimate depth at each pixel.

LIDAR: light detection and ranging sensor
shooting light beams into the environment and measuring the reflected return.
measuring the amount of returned light and time of flight of the beam.
a spinning element with multiple stacked light sources
LIDARのcomparison metrics
- Number of beams : 8, 16, 32, 64
- Points per second (it can collect) (the more detailed the 3D point cloud can be)
- Rotation rate (the faster the 3D point clouds are updated)
- Detection range (the power output of the light source)
- Field of View

最新LIDAR：High-resolution, solid-state LIDAR
No rotational component
安い：the future of affordable self-driving

RADAR: radio detection and ranging
Robust (large) Object Detection and Relative Speed Estimation
particularly useful in adverse weather
Comparison metrics: range, field of view, position and speed accuracy
Configurations:
- WFOV, short range
- NFOV, long range

Ultrasonics or sonars: sound navigation and ranging
short-range: good for parking scenarios.

Proprioceptive Sensors
GNSS: Global Navigation Satellite Systems
- GPS or Galileo

IMU: Inertial Measurement Units
- angular rotation rate, acceleration, heading

Wheel Odmetry sensor: tracks wheel velocities and orientation, estimate speed and heading rate.

Computing Hardware
self-driving computing brain: take in all sensor data, compute actions
Already existing advanced systems that do self-driving car processing:
- Nvidia's Drive PX (multiple GPUs)
- Intel & Mobileye's EyeQ (have FPGAs to accelerate parallalizable compute tasks)

Any computing brain for self-driving needs both serial and parallel compute modules.
なぜなら：image processing, object detection, mapping
GPUs, FPGA(Field Programmable Gate Array)s, custom ASIC(Application Specific Integrated Chip)s

Synchronization Hardware
GPS relies on extremely accurate timing to function, and as such can act as an appropriate reference clock when available.

Lesson 2: Hardware Configuration Design
Aggressive deceleration = 5m/s^2
Comfortable deceleration = 2m/s^2 : reasonably comfortable while still allowing the car to come to a stop quickly

Stopping distance : $d = \dfrac{v^2}{2a}$

Need sensors to support maneuvers within our ODD

Highway Analysis
Emergency stop, Maintain speed, Lane Change

Emergency stop
① If there is a blockage ahead, we want to stop in time
longitudinal coverage: 120kmph, stopping distance ~ 110m, aggressive deceleration.
Most self-driving systems aim for sensing ranges of 150 ~ 200m in front of the vehicle as a result.
②To avoid collision, either we stop or change lanes
sense at least our adjacent lanes.

Maintain Speed with Merge
Laterally: A wide 160 to 180 degree field of view is required to track adjacent lanes and a range of 40 ~ 60m is needed to find space between vehicles.

Lane Changeの横制御
一本隣だけじゃなく、もう一本隣必要。
We may need to look beyond just the adjacent lanes.
For example, what if a vehicle attempts to maneuver into the adjacent lane at the same time as we do?
We'll need to coordinate our lane change room maneuvers so we don't crash.

Urban Analysis
Emergence Stop, Maintain Speed, Lane Change
→don't need the same extent for long-range sensing
+ Overtaking（追い越し, overtake a parked car）, Turning, crossing at intersections, Passing roundabouts

Overtaking
wide short-range sensors to detect the parked car.
narrow long-range sensors to identify if oncoming traffic is approaching.

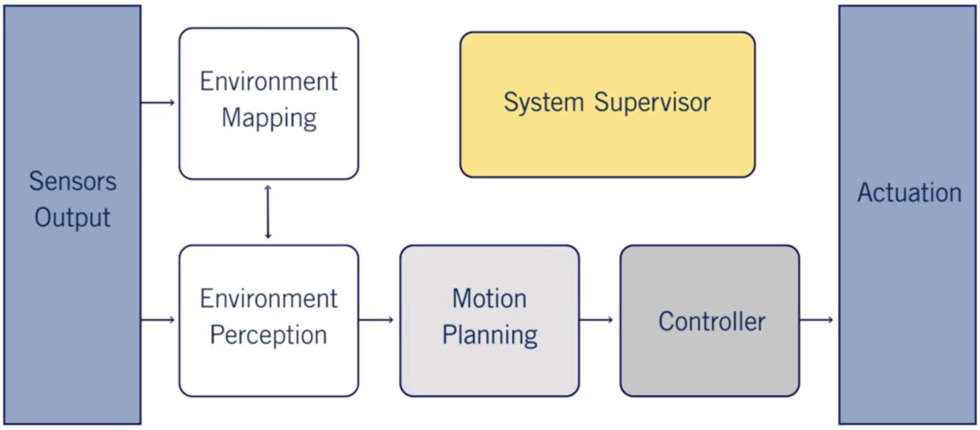
Intersections
near omni-directional sensing for all kinds of movements that can occur

Roundabouts
wide-range, short distance sensor laterally since the traffic is slow.
wide-range, short distance sensor longitudinally because of how movement around the roundabout occurs.

Overall Coverage & Sensors Analysis
The need for full 360 degrees sensor coverage on the short scale out to about 50m.
And much longer range requirements in the longitudinal direction.

Lesson 3: Software Architecture

The standard software decomposition



-Environment Perception
-Environment Mapping
-Motion Planning
-Controller
-System Supervisor

The raw sensor measurements are passed into two sets of modules (Environment perception & mapping) dedicated to understanding the environment around the car.

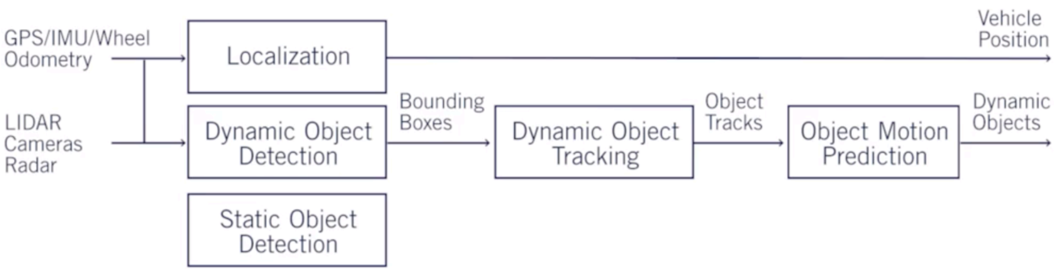
SOFTWARE ARCHITECTURE

The environment mapping module creates a set of maps which locate objects in the environment around the autonomous vehicle for a range of different uses, from collision avoidance to egomotion tracking and motion planning.

Motion PlanningのmainアウトプットI： a safe, efficient and comfortable planned path.

The Controller module takes the path and decides on the best steering angle, throttle position, brake pedal position, and gear settings to precisely follow the planned path.

The System Supervisor is also responsible for informing the safety driver of any problems found in the system.



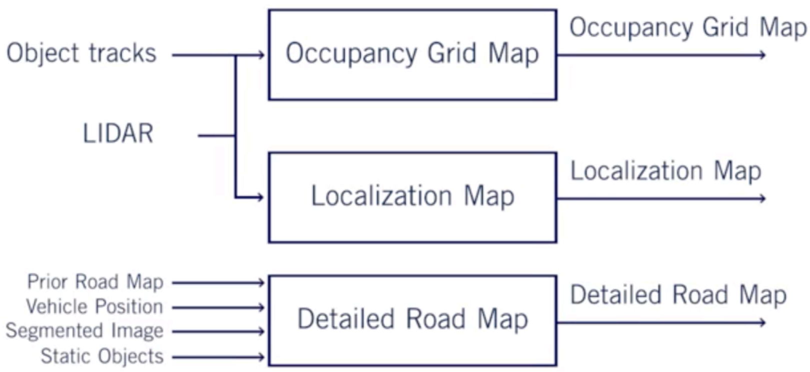
ENVIRONMENT PERCEPTION

Environment Perception

インプット：
GPS/IMU/Wheel Odometry
LIDAR/Cameras/Radar
HD Road Map
- Localization→Vehicle Position
- Dynamic Object Detection→Bounding Boxes→Dynamic Object Tracking→Object Tracks→Object Motion Prediction→Dynamic Objects

- Static Object Detection→Static Objects

Environment Mapping



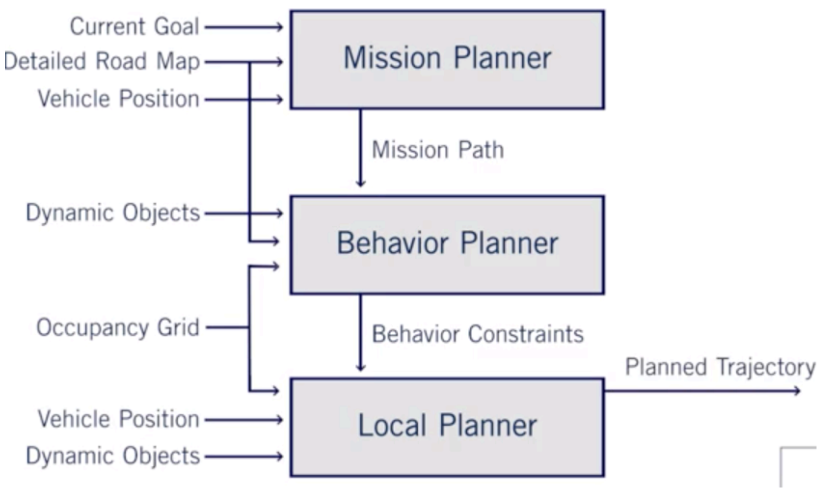
ENVIRONMENT MAPPING

-Occupancy Grid Map
-a map of all static objects in the environment surrounding the vehicle (メインLIDAR)
-Filtering LIDAR: the drivable surface（路面） points and dynamic object points are removed.
-a set of grid cells and probability that each cell is occupied
-Localization Map (LIDAR & Camera)
-Sensor data is compared to this map while driving to determine the motion of the car relative to the localization map. This motion is then combined with other proprioceptor sensor information to accurately localize the eco vehicle.

- Detailed Road Map
  - road segments, signs and lane markings
  - a combination of prerecorded data as well as incoming information from the current static environment gathered by the perception stack (Environment Perception)

Environment PerceptionとEnvironment Mappingのinteraction
For example, the perception module provides the static environment information needed to update the detailed road map, which is then used by the prediction module to create more accurate dynamic object predictions.

Motion Planning



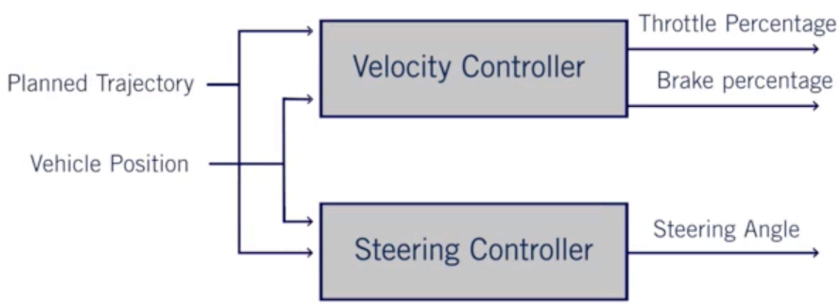
MOTION PLANNING

-Mission Planner: long term planning
-input: (Current goal, Detailed Road Map, Vehicle Position)
-output: Mission Path（the optimal sequence of road segments that connect your origin and destination, Behavior Plannerが使う）
-Behavior Planner: short term planning
-output: Decisions (例えば、whether the vehicle should merge into an adjacent lane given the desired speed and the predicted behaviors of nearby vehicles.), Constraints (例えば、how long ti remain in the current lane before switching)

- Local Planner: immediate or reactive planning

- a specific path and velocity profile. smooth, safe, and efficient given all the current constraints.

Controller



CONTROLLER

Both controllers calculate current errors and tracking performance of the local plan, and adjust the current actuation commands to minimize the errors going forward.つまりできるだけlocal plannerのplanned trajectoryに沿って進むように

System Supervisor

- Hardware supervisor
1. hardware faults: a broken sensor, a missing measurement, degraded information. 2. analyze the hardware outputs for any outputs which do not match the domain which the self-driving car was programmed to perform under. (例えば、if one of the camera sensors is blocked by a paper bag or if snow is falling and corrupting the LIDAR point cloud data.)
- Software supervisor
  - analyzing inconsistencies between the outputs of all modules

Lesson 4: Environment Representation

Environment Map Types
- Localization of vehicle in the environment : Localization point cloud or feature map
  - created using a continuous set of LIDAR points or camera image features
  - used in combination with GPS, IMU and wheel odometry by the localization module to accurately estimate the precise location of the vehicle at all times
- Collision avoidance with static objects : Occupancy grid map
  - a continuous set of LIDAR points, all static obstacles
- Path planning : Detailed road map
  - detailed positions for all regulatory elements, regulatory attributes（例えばright turn markings or crosswalks） and lane markings

Localization Map
- The difference between LIDAR maps is used to calculate the movement of the autonomous vehicle.
  - The localization map can be quite large, and many methods exist to compress its contents and keep only those features that are needed for localization.

Occupancy Grid Map
- Dynamic objects be removed: by removing all LIDAR points that are found within the bounding boxes of detected dynamic objects identified by the perception stack.
- all stationary objects such as poles, buildings, and parked cars, are shown as occupied grid cells.

Detailed Roadmap（僕が開発しているMapAPIはこれ）
3 Methods of creation:
- Fully Online (rarely used due to the complexity of creating such a map in real time)
- Fully Offline (unable to react or adapt to a changing environment)
  - highly accurate
  - 作り方：Specialized vehicles with high accuracy sensors are driven along roadways regularly to construct offline maps. Once the collection is complete, the information is then labelled with the use of a mixture of automatic labeling from static object perception and human annotation and correction.
- Created Offline and Updated Online
  - storing all the information present in a detailed roadmap called the lane length model

Right now cars are utilized maybe five percent of the time.
be able to move more riders with less vehicles.