Perception and Planning

Week 9

Autonomous Vehicles

Autonomous Vehicles (AVs)

Content:

- Driverless cars
- Ethics of driverless cars
- Driverless car systems
- Other autonomous vehicles
    - Drones
    - Underwater vehicles
    - Interplanetary rovers

What is an Autonomous Vehicles

- Vehicle that get from one point to another point without human interaction.
- Perceives the environment and moves with safety.
- Requires a number of well placed sensors that detect different things such as other vehicles, people, traffic lights, and movement of other vehicles.

What is an Autonomous Vehicles

Smart Driving Cars

<u>Level 0 (No automation)</u>
Human is in complete and sole control of safety-critical functions (brake, throttle, steering) at all times.

<u>Level 1 (Function-specific automation)</u>
Human has complete authority, but cedes limited control to the vehicle in certain normal driving or crash imminent situations. Example: electronic stability control.

<u>Level 2 (Combined function automation)</u>
Automation of at least two control functions designed to work in harmony (e.g., adaptive cruise control and lane centering) in certain driving situations. Enables hands-off-wheel and foot-off-pedal operation. **But driver still responsible for monitoring and safe operation and expected to resume control of the vehicle.** Example: adaptive cruise control in conjunction with lane centering.

<u>Level 3 (Limited self-driving)</u>
Vehicle controls all safety functions under certain traffic and environmental conditions. Human can cede monitoring authority to vehicle, which must alert driver if conditions require transition to driver control. **Driver expected to be available for occasional control**. Example: Google car

<u>Level 4 (Full self-driving automation)</u>
Vehicle controls all safety functions and monitors conditions for the entire trip. The human provides destination or navigation input but is not expected to be available for control during the trip. **Vehicle may operate while unoccupied**. Responsibility for safe operation rests solely on the automated system

NHTSA
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Examples

- Tesla CEO, Elon Musk, expects true autonomous driving by 2023-24. “We will be able to achieve true autonomous driving where you could literally get in the car, go to sleep and wake up at your destination”.
- “We may need to wait another 2 to 3 years for regulatory approval.”

Tesla Model S

Tesla Model X

GOOGLE AV

- Google AV - no steering wheel or pedals.
- Voice and/or button (or app) control.
- Range finder - Velodyne 64-beam laser.
- Generates a detailed 3D map of the environment.
- Combines maps with google maps of the world, producing different data models to other AVs.

Google’s first AV (Prius) 2009

Google Driverless AV

Google AV (waymo)

Google AV (waymo)

https://waymo.com/

Mercedes AV

- Mercedes was the first car manufacturer to develop and deploy a fully autonomous car (Eureka PROMETHEUS Project, 1987).
- The largest ever project in the field of driverless cars.
- Currently, all Mercedes-Benz cars have level-2 autonomous driving systems – the car takes control in certain situations (e.g. collision).
- Mercedes-Benz is also developing Level 3, 4 & 5 vehicles for the consumer market and expects to have them in production in 2020 – 2021.

PROMETHEUS = ***PRO****gra****M****me for a* ***E****uropean* ***T****raffic of* ***H****ighest* ***E****fficiency and* ***U****nprecedented* ***S****afety*

Mercedes AV

Driverless cars allow for new aerodynamic design concepts.

- A large forward looking windscreen (causing drag) is not necessary.

Mercedes AV

Driverless cars allow for more space efficient designs.

- No need for a console, steering wheel, pedals.

Toyota AV

Apple’s Prototype

Nissan

Nissan’s electric autonomous cabs.

Dutch EZ-10 Autonomous Shuttle (Ligier Group)

Netherlands - first to operate a self-driving shuttle in public traffic.
(http://www.driverless-future.com/)

Delphi / Audi SQ5

Driverless Cars Now

- Tesla: With Models S and X, owner can "summon" car in self-driving mode from garage or driveway.
- Delphi: In March 2015, sent an AV Audi SQ5 SUV on a coast-to coast drive -- the longest ever for an AV.
- Cadillac: "Super-cruise" feature allowing cars to steer, brake, accelerate by themselves.
- Apple: With $178 billion in cash, has announced it will jump into the white-hot AV race. ("Project Titan.")
- Nissan's all-electric AV taxi is already on sale in Europe.

Car markers with AV models?

- AV Car manufacturers:
- GM
- Ford
- VW-Audi
- Volvo
- Nissan
- Toyota
- Daimler AG
- Tesla
- SAIC Motors (Shanghai Auto. Ind. Corp.)

Technological and Idea Innovators

- Google
- Amazon
- Uber
- Apple
- Alibaba/Baidu

Benefits

1. Safety:
   – 90% of 5.5 million crashes in U.S. caused by driver error. Auto crash deaths are 8th leading cause of death in the world. 1.2 million people per year world-wide; 33,000 in U.S. – equivalent of 5 Boeing jets crashing every week.
2. Productivity/Personal Savings:
   – 50 minutes per person per day = economic value of $100 billion to $1 trillion.
   – Decline in Car Ownership: Cars now cost drivers 18% of annual income for an asset they use only 5% of the time.
3. Reduced Traffic Congestion
   - 25% of congestion due to accidents averted by AVs.
   - AVs will respond better to traffic conditions.
   - Networked AVs communicate, eliminating need to anticipate actions of other cars.

Benefits

4. Economic benefits
   - Car ownership can become obsolete.
   - Improved utilization of assets via car sharing.
   - Significantly reduces need for parking spaces, personal garage or car ports.
5. Environmental Benefits
   - Goal is for AVs to be electric or hybrid.
   - Cars account for 20% of all greenhouse gas emissions and 60% of petroleum use.
   - Fuel efficiency will improve by 10% to 40%.
5. New trillion-dollar industry
   - Provides countless opportunities for entrepreneurs to develop new technologies and services.

Drawbacks

1. Job loss in traditional industries:
   - Trucking (~3.5 million)
   - Taxis
   - Couriers
2. Loss of Revenue to Municipal Budgets:
   - From speeding or parking tickets.
   - Less need for law enforcement to monitor roadways and accidents.
   - Reduced use of public transportation.
3. Disruption to Current Land Use
   - People may move to suburbs from cities since they can be productive during commute.

Drawbacks

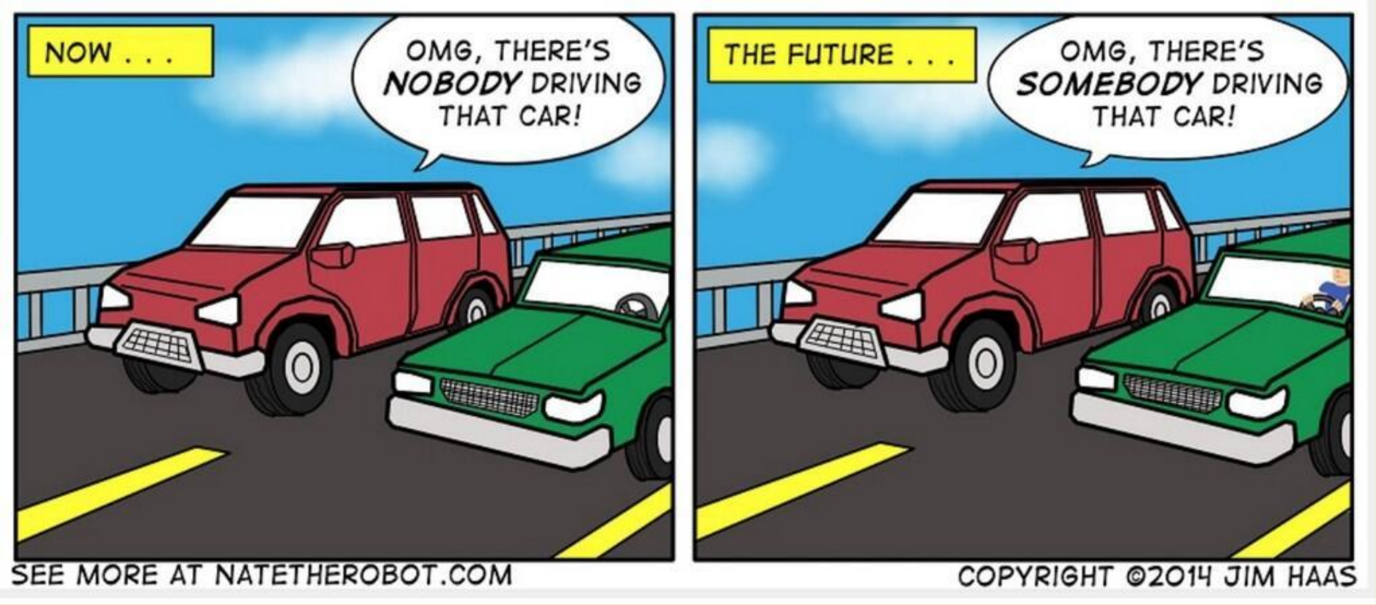
4. Although there are people who want the technology in their cars, it can cost:
   – $2,000 on average for safety-related tech (not automation)
   – $10,000 for Cruise (in Audi S4s)

5. Poor performance in adverse weather conditions.

6. Who is to blame?
   – The car manufacturer?
   – The programmer?
   – The driver?

Public Acceptance and Adoption

- Vehicle to vehicle technology cannot function ideally without adoption by the public.
- Minority vs majority



- Few legal precedents
  - Legal in NV, CA, FL, MI, and the District of Columbia.
  - Failed legislation in TX, OK, CO, AZ, OR, WI, and NH.

Ethical Considerations

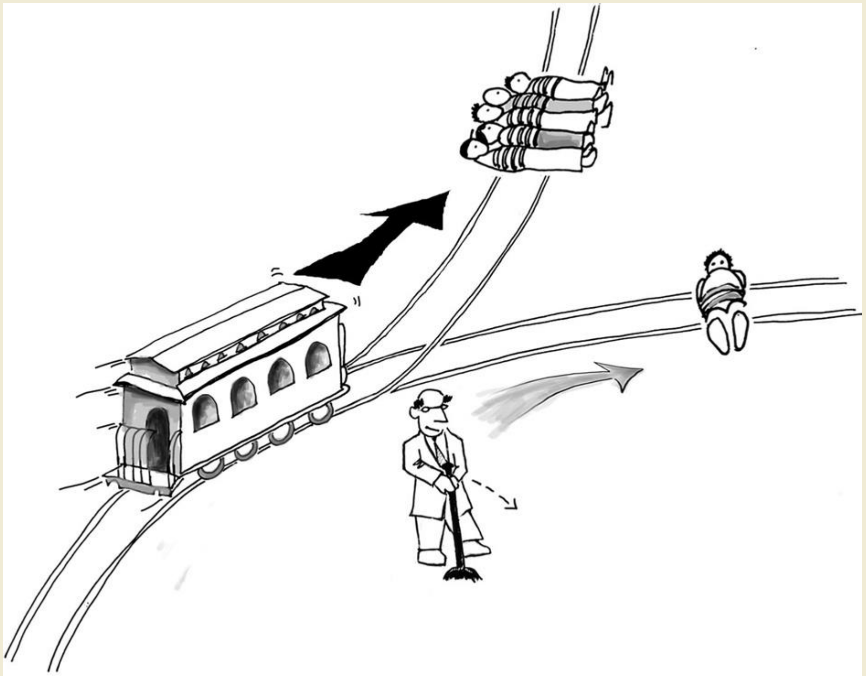
"Human drivers may be forgiven for making an instinctive but nonetheless bad split-second decision, such as swerving into incoming traffic rather than the other way into a field. But programmers and designers of automated cars don't have that luxury, since they do have the time to get it right and therefore bear more responsibility for bad outcomes."

- Patrick Lin, The Atlantic

The Trolley Problem

(A classic thought-exercise in ethics)

- A trolley's brakes have failed.
- You are controlling the signal switch.
- If you do nothing, five people will be killed.
- If you activate the switch, only one person will be killed.
- What do you choose to do?
- Critical distinction: Allowing death versus causing death?



Utilitarian Analysis

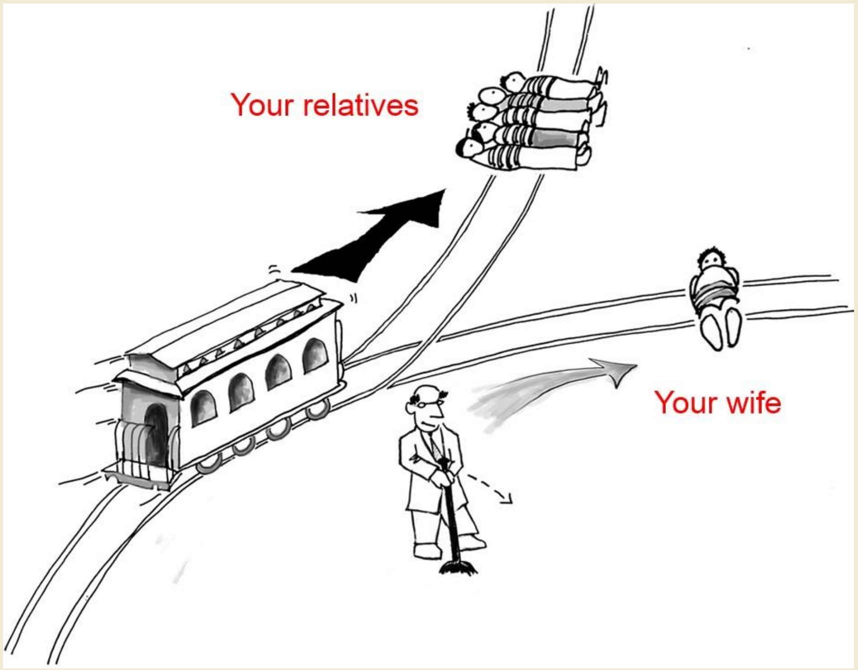
Utilitarianism is a moral theory that advocates actions that promote overall happiness or pleasure and rejects actions that cause unhappiness or harm.

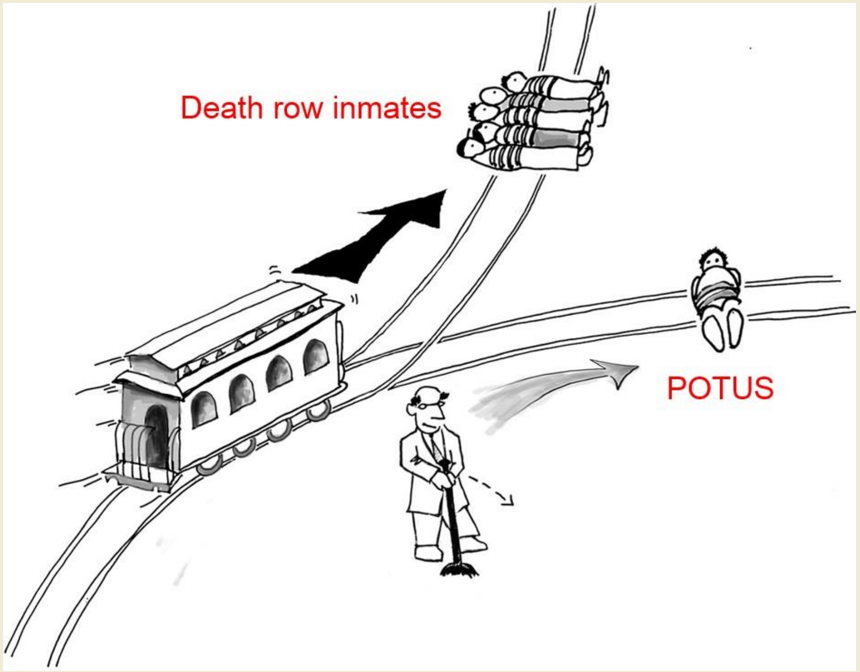
Some of the key points are:

- Weigh the pros and cons of each potential outcome to determine the net change in overall welfare.
- Pick the outcome with greatest net increase (or least decrease) in welfare.
- Due to its objectiveness, it is theoretically possible to implement this in a computer system.

The Trolley Problem

When the identities of the actors change…

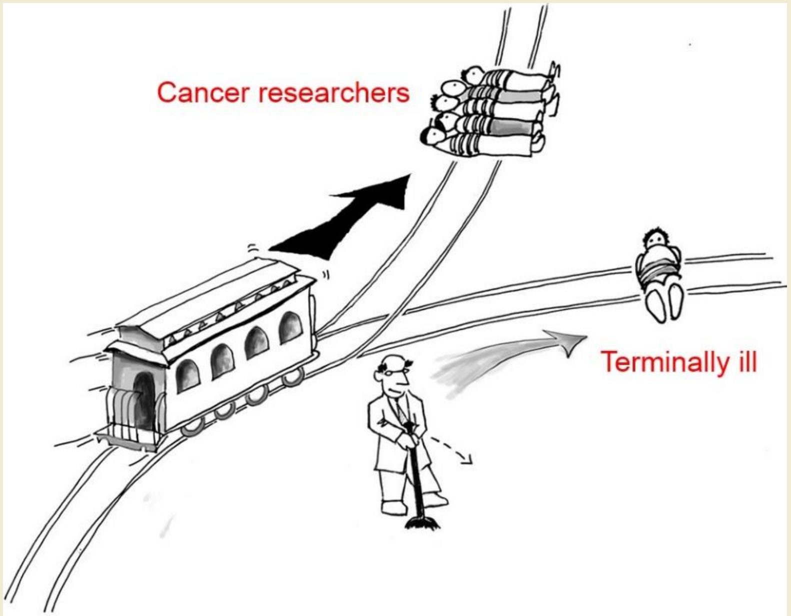




Problems with Utilitarian Analysis

Observations:

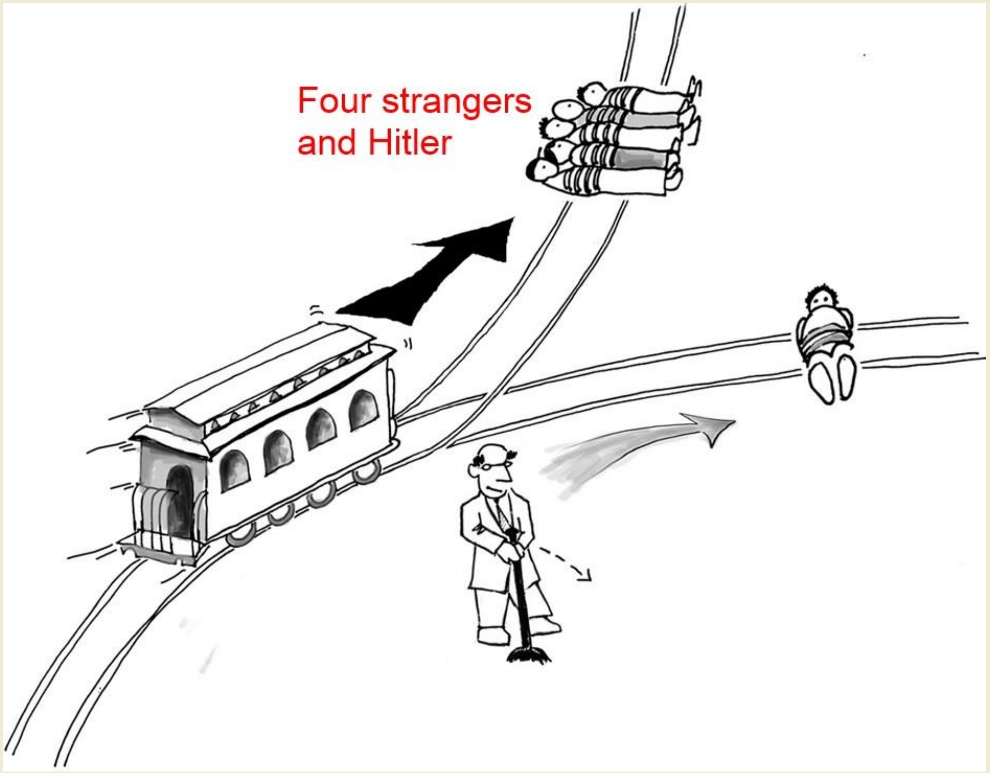
- Utilitarian Analysis is ineffective when information is omitted.
- A truly accurate analysis may require valuing one human life over another.
- The “least bad” outcome may still result in the loss of life.



Another Problem: Consequentialism

While we are free to choose our actions, we are not free to choose the consequences of our actions.

– Stephen R. Covey



Without complete information and the gift of hindsight, a decision that results in a net gain of welfare in the short run may turn out to be a very poor decision in the long run.

A New Class of Victims

- There will be an inherent shift in the makeup of automobile accident victims.
- Likely a decrease in driver deaths and an increase in pedestrian and cyclist deaths.
- Great news for some people, bad news for others.
- An ethical conundrum: Can we accept an increase in the death rate of certain groups of people if it means a decrease in the overall death rate?

Random Outcome Generator

A "fair" solution:

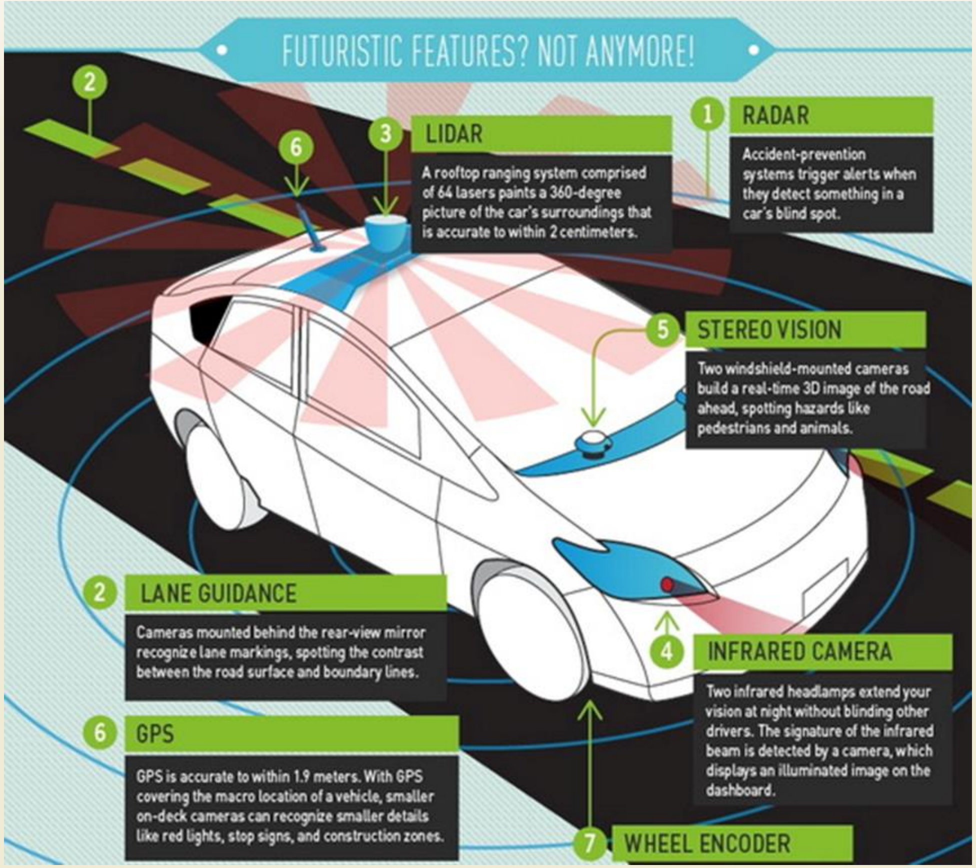
Generate a list of potential outcomes, then roll the dice:

1. Swerve to the right, potentially killing a cyclist.
2. Swerve to the left, potentially killing two pedestrians.
3. Continue forward into the path of an oncoming vehicle, potentially killing yourself and its occupant(s).

Easing Public Apprehensions

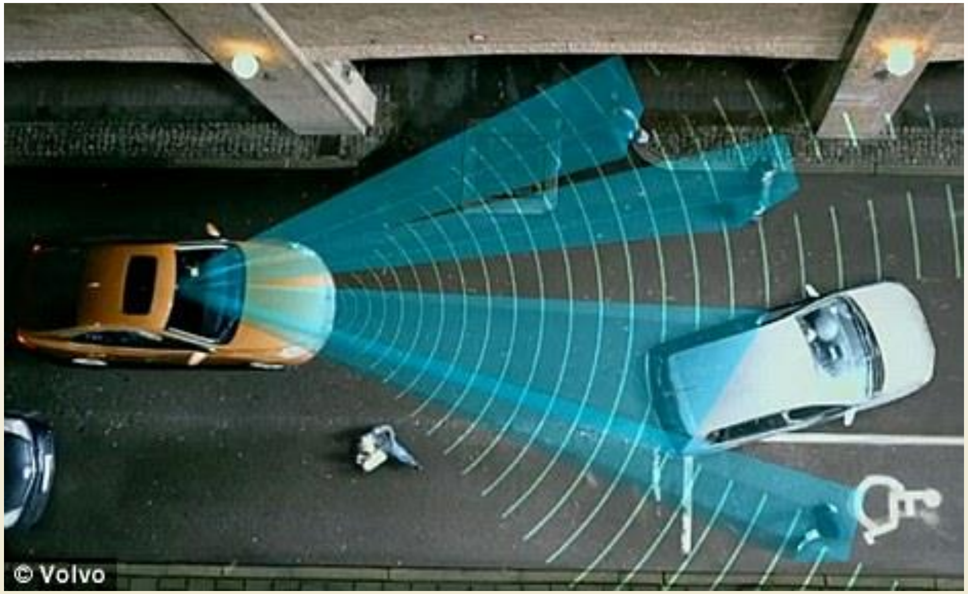
- How many more lives per year must be saved for the public to embrace a driverless revolution?
- Manufacturers will need to be upfront with the details of the decision-making systems piloting the vehicles.
- Will there be override or customization capabilities?
- Delayed Feedback Problem: There will be a significant period of time before we’ve collected enough data to determine the effectiveness of a driverless initiative.

Car and AV Technology



- Anti-Lock Brakes
- Electronic Stability control
- Adaptive cruise control
- Lane-departure warning system
- Self parking
- Automated guided vehicle systems
- Lidar-Systems(with google cars) or Cruise Automated Systems(Audi)
- Infrared cameras.

Technologies



- Lane departure warning
  - The car of lazy or inattentive drivers can automatically be moved
- Blind spot monitoring
  - Warn if cars are in blind spots
- Pedestrian detection
  - Automatic brake or warning
- Adaptive cruise control + forward collision warning
  - Car stays a safe distance behind cars ahead of it
  - Warns or takes action in case of danger

Cruise Systems

Features:

- Cameras and Radars to map out surroundings(including other vehicles)
- Used mainly for highway scenarios.
- Steering wheel motor mounted to steering column.
- Adaptive speed control.
- Collision avoidance
- RP-1 sensors
- Will be made in future for other vehicles.

The Lidar System

Features:

- Vertical and horizontal setup of the system possible
- Image acquisition with fully integrated NIKON DSLR camera.
- 3D mode of the VZ scanner with continuous rotation of the scanning head for highly efficient mobile data acquisition.
- 360 degree static scanning.
- Mainly used by Google Inc. for detecting the surroundings of the vehicle

Apples and Oranges

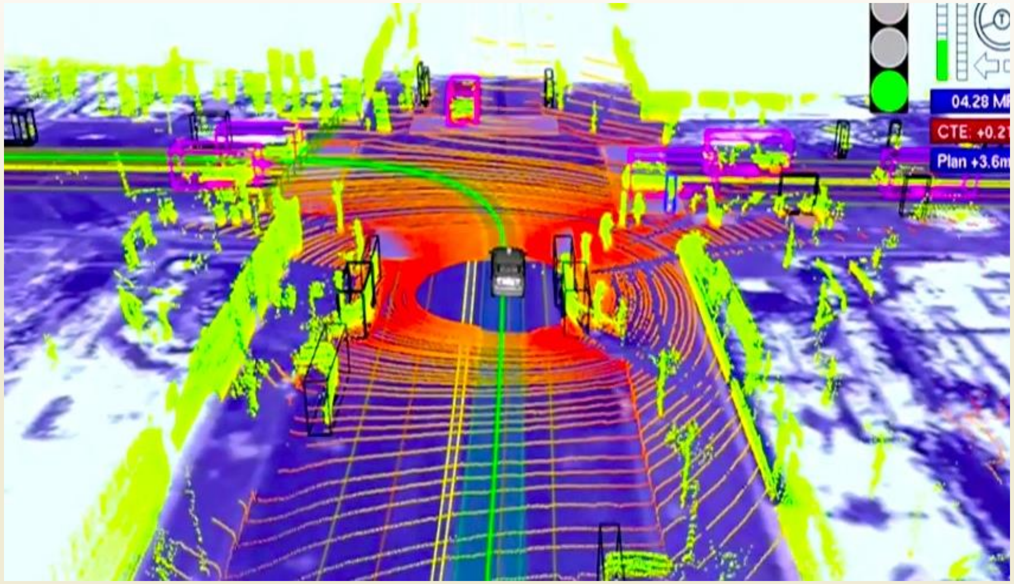
Lidar System:

- $70k system.
- Can be used in basically anywhere.
- Design is very bulky and heavy.
- Fully autonomous.

Cruise System:

- $10k system(installed).
- Mainly for highway scenarios.
- Design is relatively small and lightweight.
- Not fully autonomous .

AV Algorithms



A combination of:

- 3-D imaging with multiple 1064 nm lasers.
- Edge detection algorithm.
- Object detection algorithm.
- Motion detection algorithm
- Tracking algorithm.

AV Algorithms

- What does an autonomous vehicle need?
  - AV usually have high-level goals provided to them.
  - From each goal they must plan how to accomplish the goal:
    - Mission planning – how to accomplish the goal.
    - Path planning – how to reach a given location.
    - Sensor interpretation – determining the environment given sensor input.
    - Object detection to distinguish between people, cars, road, trees, …
    - Obstacle avoidance and terrain sensing.
    - Failure tolerance, failure handlings, and recovery from failure.

Mission Planning

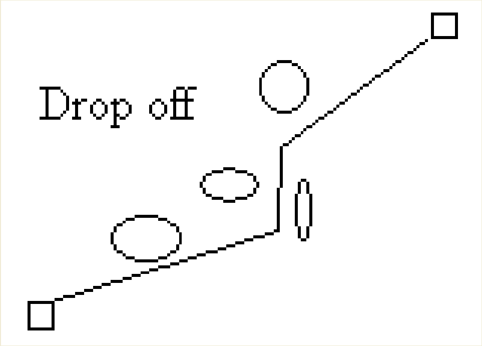
- As the name implies, this is largely a planning process
  - Given goals, how to accomplish them?
    - this may be through rule-based planning, plan decomposition, or plans may be provided by the human controller.
  - For AV, in many cases, the mission goal is simple: go from point A to point B so that no planning is required.
  - For a mobile robot (not an autonomous vehicle), the goals may be more diverse
    - reconnaissance and monitoring
    - search (e.g., find enemy locations, find buried land mines, find trapped or injured people)
    - go from point A to point B but stealthily
    - monitor internal states to ensure mission is carried out

Path Planning

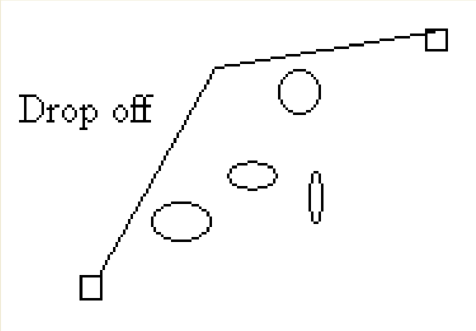
- How does the vehicle get from point A to point B?
  - Are there obstacles to avoid? Can obstacles move in the environment?
  - Is the terrain going to present a problem?
  - Are there other factors such as dealing with poor visibility?
- Path planning is largely geometric and includes
  - Straight lines
  - Following curves
  - GPS tracking
- Additional issues are
  - How much of the path can be viewed ahead?
  - Is the AV going to generate the entire path at once, or generate portions of it until it gets to the next point in the path, or just generate it on the fly?
  - If the AV gets stuck in a dead end, can it backtrack?

On Path Planning

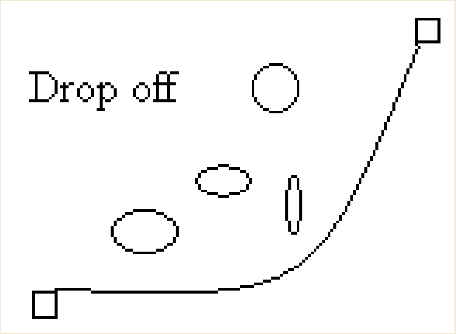
- The robot must balance the desire for the safest path, the shortest distance path, and the path that has fewer changes of orientation
  - Variations of the A* algorithm (best-first search) might be used, particularly with GPS.
  - Heuristics might be used to evaluate safety versus simplicity versus distance.



Shortest path
With many changes



Simplest path
but not safe



Safest path

Following a Path

- Once a path is generated, the AV must follow that path, but the technique will differ based on the road or terrain.
  - For roadways, path planning is often one of just following the road
    - using a camera, find the lines that make up the roadway's edges or lanes, and use these as boundaries to move within.
  - For an all-terrain vehicle
    - GPS must be used although this may not be 100% accurate and may not perceive hazards.

Sensor Interpretation

- Sensors are primarily used to
  - ensure the vehicle is following an appropriate path (e.g., roadway)
  - and to detect and avoid objects.
- Outdoor AVs commonly use cameras and lasers to “see” the road and other vehicles, etc.
- Additionally, GPS might be useful
  - so that the can interpret input from multiple sensors.
  - To supplement visual sensors in adverse situations (i.e. dirt or snow covering the road, heavy fog,…).
  - To achieve fault tolerance (i.e. a failed visual sensor).

Performing Sensor Interpretation

- There are many forms:
  - Simple neural network recognition
    - more common if we have a single source of input, e.g., camera, so that the NN can respond with "safe" or "obstacle", or to recognize objects.
  - Fuzzy logic controller
    - can incorporate input from several sensors.
  - Bayesian network and hidden Markov models
    - for single or multiple sensors.
  - Blackboard/KB approach
    - post sensor input to a blackboard, let various agents work on the input to draw conclusions about the environment
- Since sensor interpretation needs to be real-time, we need to make sure that the approach is not overly elaborate.

Obstacle Avoidance

- What happens when an obstacle is detected by sensors? It depends on the situation.
  - The AV might stop, re-plan and resume.
  - Or it might slow down and change directions to avoid the obstacle (e.g., steer right or left) while making sure it does not drive off the road.
  - If obstacle is moveable then may push it gently out of the way.
  - An underwater vehicle or an air-based vehicle may change depth/altitude.
- While obstacle avoidance is a low-level process, it may impact higher level processes (e.g., goals) so replanning may take place at higher levels.

Failure Handling/Recovery

- If the vehicle is not 100% autonomous, it may wait for new instructions.
- If the vehicle is on its own it must first determine if the obstacle is going to cause the goal-level planning to fail.
  - if so, replanning must take place at that level taking into account the new knowledge of an obstacle.
  - if not, simple rules might be used to get it around the obstacle so that it can resume.
- If a failure is more severe than an obstacle (e.g., power outage, sensor failure, uninterpretable situation)
  - then the ultimate failsafe is to stop the AV and have it send out a signal for help.
- Adding fault tolerance
  - Redundant and/or complimentary sensors.
  - Have alternative plans (i.e. use the next best solution).

Autonomous Ground Vehicles

- We can break AVs into four categories:
  - Road-based autonomous automobiles
    - Automatic cars are programmed to drive on road ways with marked lanes and possible must contend with other cars.
  - All-terrain autonomous automobiles
    - Automatic cars/jeeps/SUVs/tanks programmed to drive off road and must contend with different terrains with obstacles like rocks, hills, etc.
  - Crawlers
    - Like all-terrain cars except that they use multiple legs instead of wheels/treads to maneuver.

Road-Based AVs

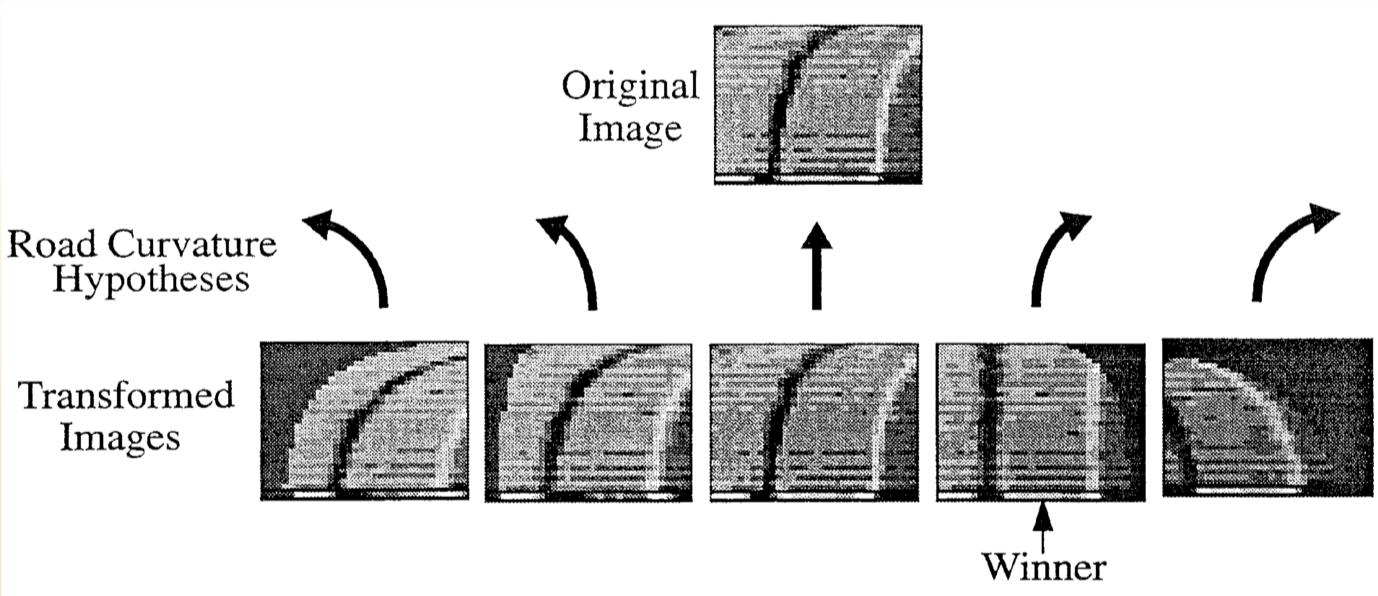
- We currently do not have any truly autonomous road-based AVs in the consumer market but many research vehicles have been tested.
  - NavLab5 (CMU) – performed “no hands across America”
    - the vehicle traveled from Pittsburgh to San Diego with human drivers only using brakes and accelerator, the car did all of the steering using RALPH.
  - ARGO (Italy) drove 2000km in 6 days
    - using stereoscopic vision to perform lane-following and obstacle avoidance, human drivers could take over as needed, either complete override or to change behavior of the system (e.g., take over steering, take over speed).

More Road-Based AVs

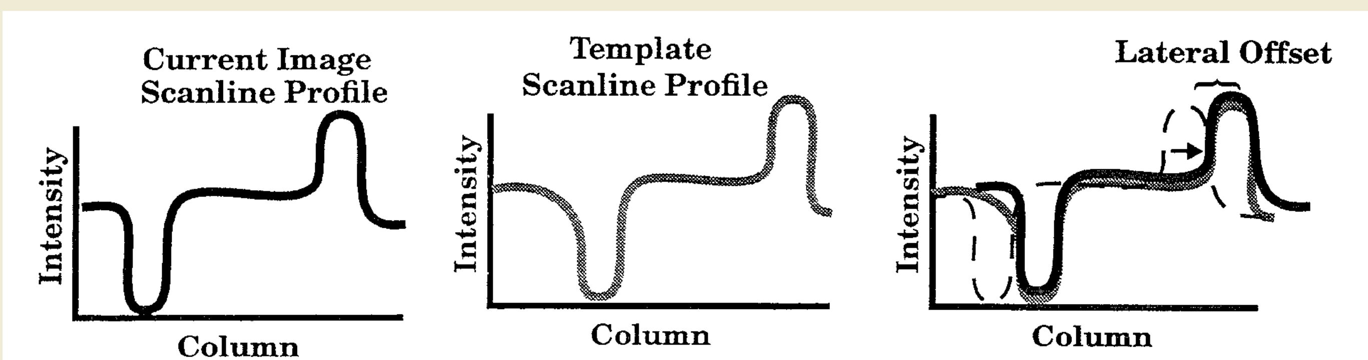
- Both NavLab and ARGO would drive on normal roads with traffic.
- The CMU Houston-Metro Automated bus was designed to be completely autonomous.
  - But to only drive in specially reserved lanes for the bus so that it did not have to contend with other traffic.
  - Two buses tested on a 12 km stretch of Interstate 15 near San Diego, a stretch of highway designated for automated transit.
  - As with NavLab, the Houston-Metro buses use RALPH (see the next slide).
- CityMobile – European sponsored approach for vehicles that not only navigate through city streets autonomously but perform
  - deliveries of people and goods.
- For such robots, the "mission" is more complex than just go from point a to point b, these AVs have higher level planning.

RALPH

- **R**apidly **A**dapting **L**ateral **P**osition **H**andler
  - Steering is decomposed into three steps
    - Sampling the image (the painted lines of a road, the edges/berms/curbs).
    - Determining the road curvature.
    - Determining the lateral offset of the vehicle relative to the lane center.
  - The output of the latter two steps are used to generate steering control.
  - Image is sampled via camera and A/D convertor board.
    - the scene is depicted in grey-scale along with enhancement routines.
    - a trapezoidal region is identified as the road and the rest of the image is omitted (as unimportant).
  - RALPH uses a “hypothesize and test” routine to map the trapezoidal region to possible curvature in the road to update its map (see the next slide).

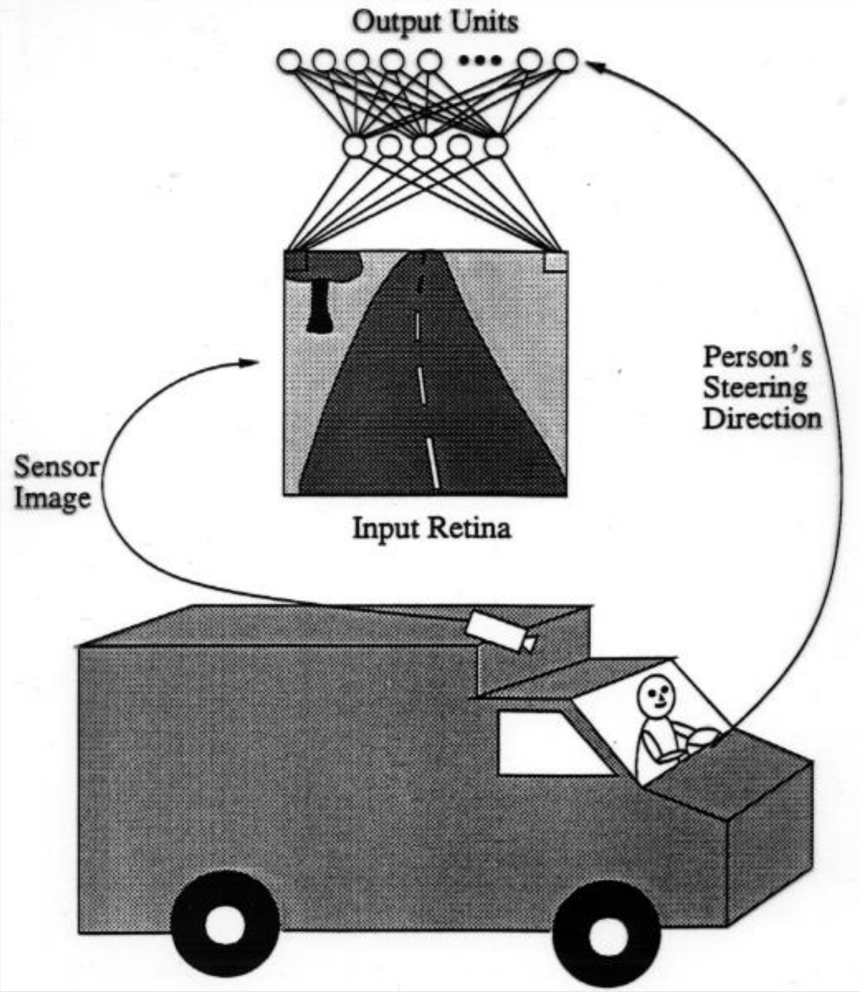


- The curvature is processed using a variety of different techniques and summed into a “scan line”.
  - RALPH uses 32 different templates of “scan lines” to match the closest one which then determines the lateral offset (steering motion).



Another Approach: ALVINN

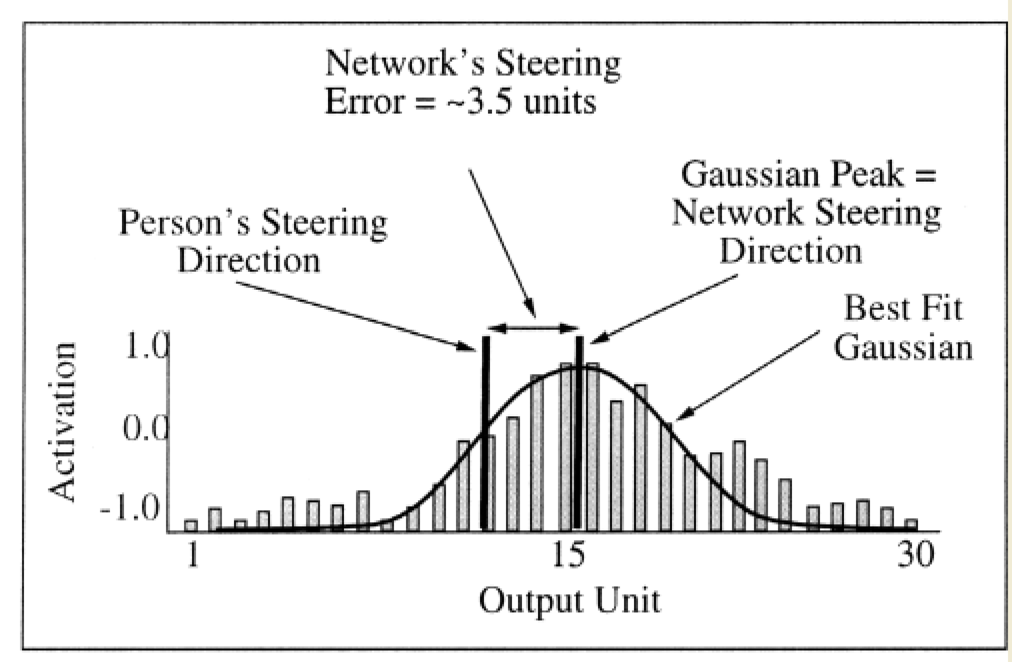
- A different approach is taken in ALVINN which uses a trained neural network for vehicular control.
  - The neural network learns steering actions based on camera input.
    - The neural network is trained by human response.
    - That is, the input is the visual signal and the feedback into the backprop algorithm is what the human did to the steering wheel.



Training

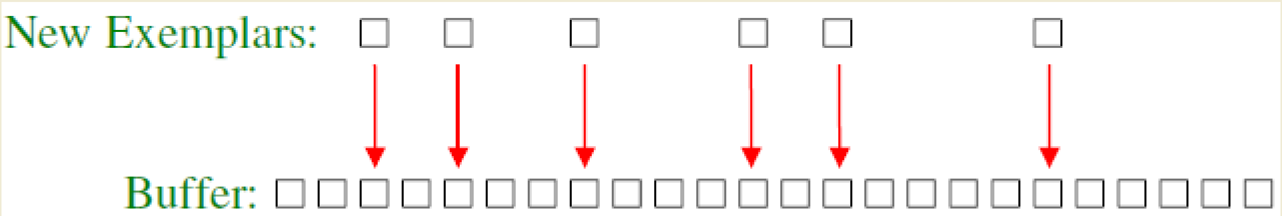
- Training feedback combines the actual steering as performed by the human with a Gaussian curve to denote “typical” steering
  - Computed error for backprop is
    - | actual steering – Gaussian curve value |

- Additionally, if the human drives well, the system doesn’t learn to make steering corrections.
  - Therefore, video images are randomly shifted slightly to provide the NN with the ability to learn that keeping a perfectly straight line is not always desired.



Over Training

- As we discussed when covering NNs, performing too many epochs of the training set may cause the NN to over train (overfit).
  - Here the problem is that the NN may forget how to steer with older images as training continues.
  - The solution generated is to keep a buffer for older images along with the new images.
    - the buffer stores 200 images.
    - 15 old images are discarded for new ones by replacing images with the lowest error and/or replacing images with the closest steering direction to the current images.

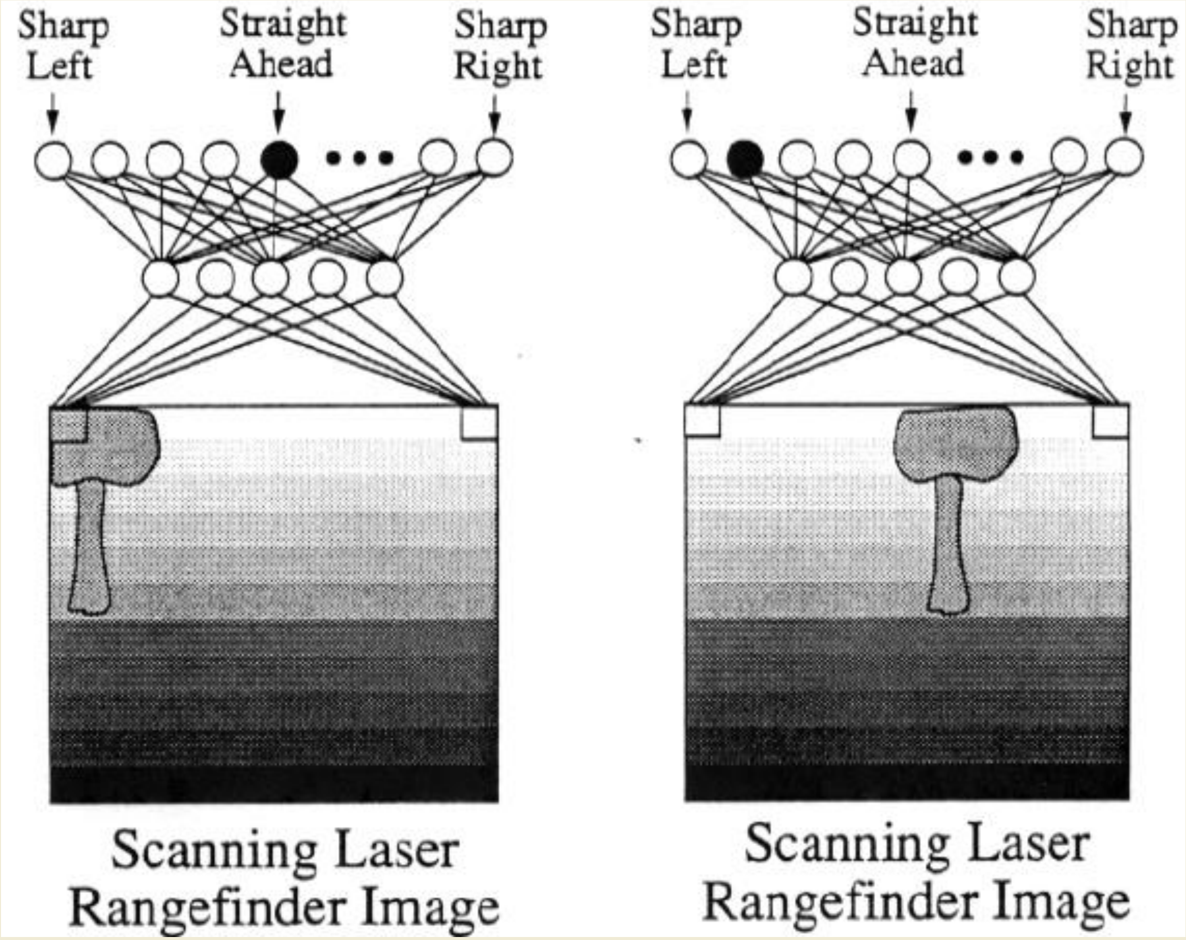


Training Algorithm

- Take current camera image +14 shifted/rotated variants each with computed steering direction.
  - Replace 15 old images in the buffer with these 15 new ones
  - Perform one epoch of backprop.
  - Repeat until predicted steering reliably matches human steering.
- The entire training only takes a few minutes although during that time, the training should encounter all possible steering situations.
  - Two problems with the training approach are that
    - ALVINN is capable of driving only on the type of road it was trained on (e.g., black pavement instead of grey).
    - ALVINN is only capable of following the given road, it does not learn paths or routes, so it does not for instance turn onto another road way.

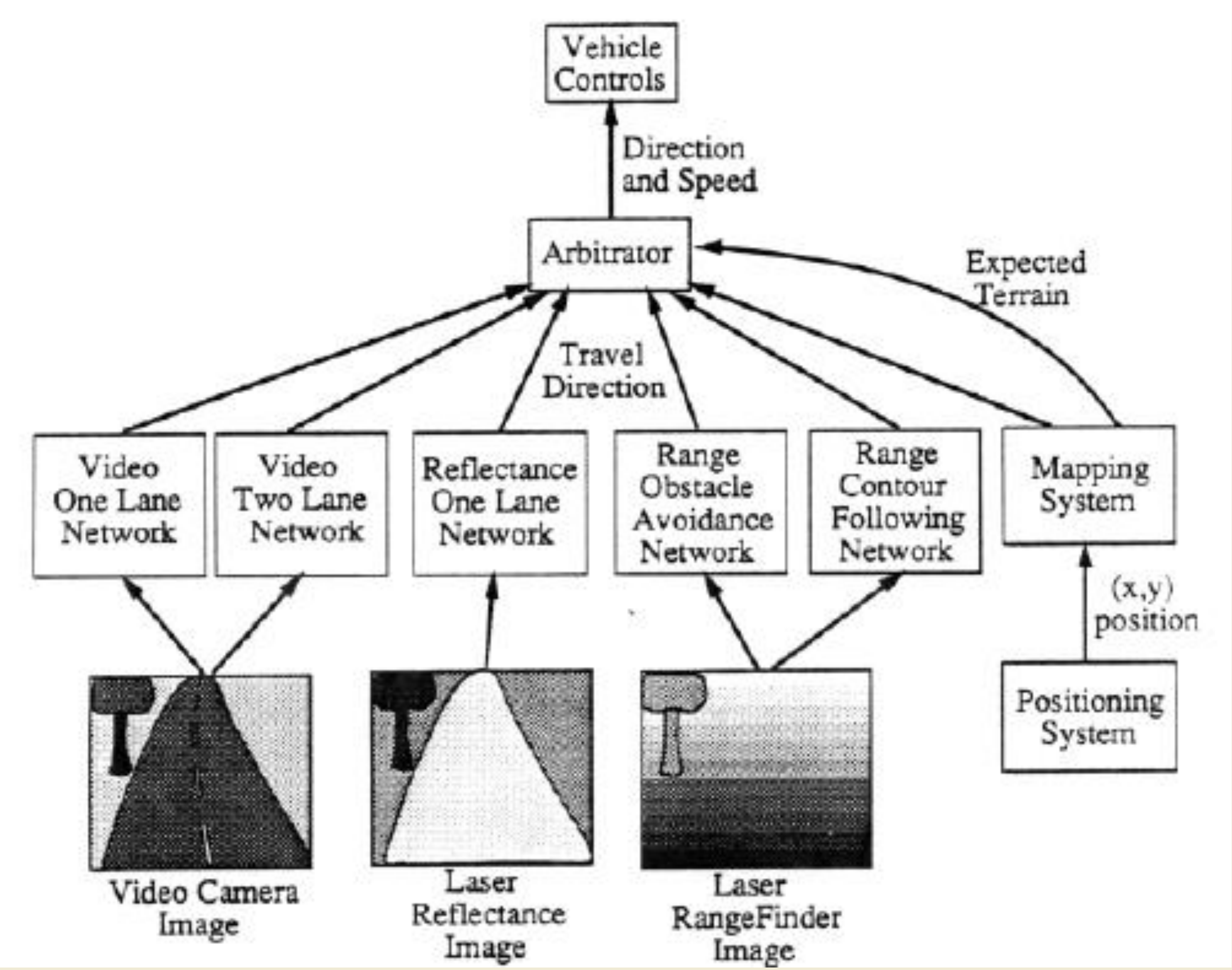
More on ALVINN

- To further enhance ALVINN, obstacle detection and avoidance can be implemented by
  - using a laser range finder to detect obstacles in the roadway.
  - train the system on what to do when confronted by an obstacle (steer to avoid, stop).
    - ALVINN can also drive at night using a laser reflectance image.



ALVINN Hybrid Architecture

By combining the steering NN, the obstacle avoidance NN, a path planner, and a higher level arbiter, ALVINN can be a fully autonomous ground vehicle.



Stanley

- We wrap up our examination of autonomous ground vehicles with Stanley, the 2005 winner of the DARPA Grand Challenge road race.
  - Based on a VW Touareg 4 wheel vehicle.
  - DC motor to perform steering control.
  - Linear actuator for gear shifting (drive, reverse, park).
  - Custom electronic actuator for throttle and brake control.
  - Wheel speed, steering angle sensed automatically.
  - Other sensors are:
    - Five SICK laser range finders (mounted on the roof at different tilt angles) which can cover up to 25m.
    - A color camera for long distance perception.
    - Two RADAR sensors for forward sensing up to 200m.

Images of Stanley

The top-mounted sensors (lasers)
Computer control mounted in the back on shock absorbers
Actuators to control shifting

Stanley's lasers can find obstacles in a cone region in front of the vehicle up to 25 m

Stanley Software

- There is no centralized control, instead there are modules to handle each subsystem (approximately 30 of them operating in parallel).
  - Sensor data are time stamped and passed on to relevant modules.
  - The state of the system is maintained by local processes, and that state is communicated to other modules as needed.
  - Environment state is broken into multiple maps.
    - laser map
    - vision map
    - radar map
  - The health of individual modules (software and hardware) are monitored so that modules can make decisions based in part on the reliability of information coming from each module.

Processing Pipeline

- Sensor data is time stamped, stored in a database of course coordinates, and forwarded.
- Perception layer maps sensor data into vehicle orientation, coordinates and velocities.
  - This layer creates a 2-D environment map from laser, camera and radar input.
  - Road finding module allows vehicle to be centered laterally.
  - Surface assessment module determines what speed is safe for travel (based on the roughness of the road, obstacles sited, and on whether the camera image is interpretable).
- The control layer regulates the actuators of the vehicle, this layer includes:
  - Path planning to determine steering and velocity needed.
  - Mission planning which amounts to a finite state automata that dictates whether the vehicle should continue, stop, accept user input, etc.
- Higher levels include user interfaces and communication.

Sensors

- Lasers are used for terrain labeling
  - Obstacle detection.
  - Lane detection and orientation (levelness).
    - these decisions are based on pre-trained hidden Markov models.
- Lasers can detect obstacles at a maximum range of 22m which is sufficient for Stanley to avoid obstacles if traveling no more than 25 mph.
  - The color camera is used to longer range obstacle detection by taking the laser mapped image of a clear path and projecting it onto the camera image to see if that corridor remains clear.
    - obstacle detection in the camera image is largely based on looking for variation in pixel intensity/color using a Gaussian distribution of likely changes.
  - If the camera fails to find a drivable corridor, speed is reduced to 25 mph so that the lasers can continue to find an appropriate path.

Path Planning

- Prior to the race, DARPA supplied all teams with a RDDF file of the path
  - This eliminated the need for global path planning by Stanley
  - What Stanley had to do was:
    - Local obstacle avoidance.
    - Road boundary identification to stay within the roadway.
    - Maintain a global map (aided by GPS) to determine where in the race it currently was.
      - Note that since there is some degree of error in GPS readings, Stanley had to update its position on the map by matching the given RDDF file to its observation of turns in the road.
    - Perform path smoothing to make turns easier to handle and match predicted road curvature to the actual road.

Higher Level Planning

- Unlike ordinary AVs, this did not really affect Stanley
  - Stanley's only goal was to complete the race course in minimal time
    - Path planning could be largely omitted.
    - Obstacle avoidance, lane centering and trajectory computations were built into lower levels of the processing pipeline.
    - Updating the map of its location was important.
  - Stanley would drop out of automatic control into human control if needed (no such situation arose) or it would stop if commanded by DARPA
    - This could arise because Stanley was being approached or was approaching another vehicle, pausing the vehicle would allow the vehicles to all operate with plenty of separation – Stanley was paused twice during the road race.

The DARPA Grand Challenge Race

- The race was approximately 130 miles in dessert terrain that included wide, level spans and narrow, slanted and rocky areas.
- 2 hours before the race, teams were provided the race map, 2935 GPS coordinates, and associated speed limits for the different regions of the race.
  - Stanley was paused twice, to give more space to the CMU entry in front of it.
  - After the second pause, DARPA paused the CMU entry to allow Stanley to go past it.
- Stanley completed the race in just under 7 hours averaging 19.1 mpg having reached a top speed of 38 mph
  - 195 teams registered, 23 raced and only 5 finished.

Autonomous Submarines

- Unlike the ALVs, AUVs (U = underwater) are more common
  - Unlike the land vehicles, AUVs have added complexity
    - 3-D environment
    - water current
    - lack of GPS underwater
  - AUVs can be programmed to reach greater depths than human-carrying submarines.
  - AUVs can carry out such tasks as surveillance and mine detection, or they may be exploration vessels.
  - One easy aspect of an AUV is failure handling, if the AUV fails, all it has to do is surface and send out a call for help .
    - if the AUV holds air on board, its natural state is to float on top of the water, so the AUV will not sink unless it is punctured or trapped underneath something.

Autonomous Space Probes

- Most of our space probes are not very autonomous
  - They are too expensive to risk making mistakes in decision making
    - i.e. orbital paths are computed on Earth,
- However, due to the distance and time lag for signals to reach the space probes, the probes must have some degree of autonomy
  - They must monitor their own health.
  - They must control their own rockets (firing at the proper time for the proper amount of time) and sensors (e.g., aiming the camera at the right angle).
- Probes have reached as far as beyond Neptune (Voyager II), Saturn (Cassini) and Jupiter (Gallileo).
  - Signal travels takes up to 19 hours (Voyager 1, one way) to reach earth.

Mars Rovers

- Related to the ground-based AVs, Spirit and Opportunity are two small ground all-terrain AVs on Mars that were launched in 2003.
  - The most remarkable thing about these rovers is their durability
    - their lifetime was estimated at 3 months but one is still functioning 15 years on.
  - Mission planning is entirely dictated by humans but path planning and obstacle avoidance is left almost entirely to the rovers themselves.
    - new software can be uploaded allowing us to reprogram the rovers over time.
  - The rovers can also monitor their own health (predominantly battery power and solar cells).

Stanford CART '73

- We have come a long way since the beginnings of Autonomous Space Vehicles.
  - Stanford CART, AI Laboratory / CMU (Moravec)
  - Designed to simulate a remote controlled Moon rover.

Classical Paradigm
Stanford Cart

1. Take nine images of the environment, identify interesting points in one image, and use other images to obtain depth estimates.
2. Integrate information into global world model.
3. Correlate images with previous image set to estimate robot motion.
4. On basis of desired motion, estimated motion, and current estimate of environment, determine direction in which to move.
5. Execute the motion.

Some Questions

- Should human and AVs be driving on the same roads at the same times?
  - If we could switch over to nothing but AVs, it might be safer, but it is doubtful that humans will give up their right to drive themselves for some time.
- How reliable can an AV be?
  - Since we are talking about excessive speeds (e.g., 50 mpg), a slight mistake could cost many lives.
- How reliable can AVs be in combat situations?
  - Again, a mistake could costs many lives by for instance firing on the wrong side.
- AVs certainly are useful when we use them in areas that are too dangerous or costly for humans to reach/explore
  - Space probes and rovers, exploring the ocean depths or in volcanoes, bomb deactivation robots, rescue/recovery robots.

Some Questions

- AVs? Long way away???
- Human-level responses?
  - Steering, acceleration and braking control are adequate when terrain is not too difficult and when there is little to no traffic around.
- Human-level reasoning?
  - Path planning and obstacle avoidance are acceptable.
  - Mission planning is questionable.
  - Failure handling and recovery are primitive.
    - the current AVs do not have the capability to reason anew.
- Ethics of AVs?
  - Programming AVs to make choices involving death or injury is difficult.

CONCLUSIONS

- AVs will change our world.
- Regulations needed to earn public trust.
- AV safety will prompt acceptance.
- As AVs become computerized and networked, cyber risk will be a key concern.
- With increase of cyber risk, cyber insurance will be required.
- Insurers may try to match exposure to premiums, and individually tailor policies to fleets and individuals.

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