DD2410

Lecture slides

Sensing and Perception

Why sensors?

Why sensors?

- Sensors are needed to cope with the uncertainty and provide an estimate of environment and “robot state”
- Uncertainty in the layout of the environment due to lack of models or unknown dynamics
- Execution of commands is uncertain due to imperfect actuation

Sensors on Waymo's car?

Example at CAS@KTH MetraLabs Rosie

- Odometry
- Laser
- 2 PrimeSense RGB-D
- Bumper

Proprioceptive sensor

Encoders

- Measures rotation of a joint/wheel
  - Compare speed sensor on a bike (magnet on a spoke and a sensor on the fork)
- Industrial robot equipped with encoders that give the position of the joints
- **Almost all mobile robots have them on the motors to**
  - **Control the speed of the wheels**
  - **Estimate the motion of the platform**

IMU

- Gyro
- Accelerometer
- Magnetometer

(Rate) gyro

- Measures rotation speed [rad/s]
- Can be used to get the orientation. How?

(Rate) gyro

- Measures rotation speed [rad/s]
- Can be used to get the orientation. How?
  - Integrate!
  - Often temperature dependent
  - Noise and changing scale/offset → angle estimates drift with time

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- Protects hard drives, activates airbags, etc
- How to get heading? What heading?

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    - Cannot determine rotation around vertical
    - Cannot tell gravitation from acceleration
- How to get position?

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- Protects hard drives, activates airbags, etc
- How to get heading? What heading?
  - Detect vertical direction
  - Limitations?
    - Cannot determine rotation around vertical
    - Cannot tell gravitation from acceleration
- How to get position?
  - Integrate twice
  - Super sensitive to noise
  - Very important to remove gravity → need to know orientation

Compass /magnetometer

- A very old navigation tool!
- Now available in solid state technology
- Very powerful to know your heading in absolute coordinate system
- Problems?

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- Now available in solid state technology
- Very powerful to know your heading in absolute coordinate system
- Problems?
  - Many other things creating magnetic fields → disturbances

IMU – Inertial Measurement Unit

- Combines accelerometers and gyros
- Often combined with magnetometers (why?)
- Now also often with GPS
- Ex: xsense.com

Study at home (OPTIONAL)

- Download and play with the SensorFusion App
  - Works only for Android so find an Android friend
  - http://www.sensorfusion.se/sfapp/
  - Download from Google Play

Scale and bias

- You typically measure a voltage (e.g. 0-5V)
- Voltage proportional to the quantity in question
- What do you need to know to go from voltage to your quantity?

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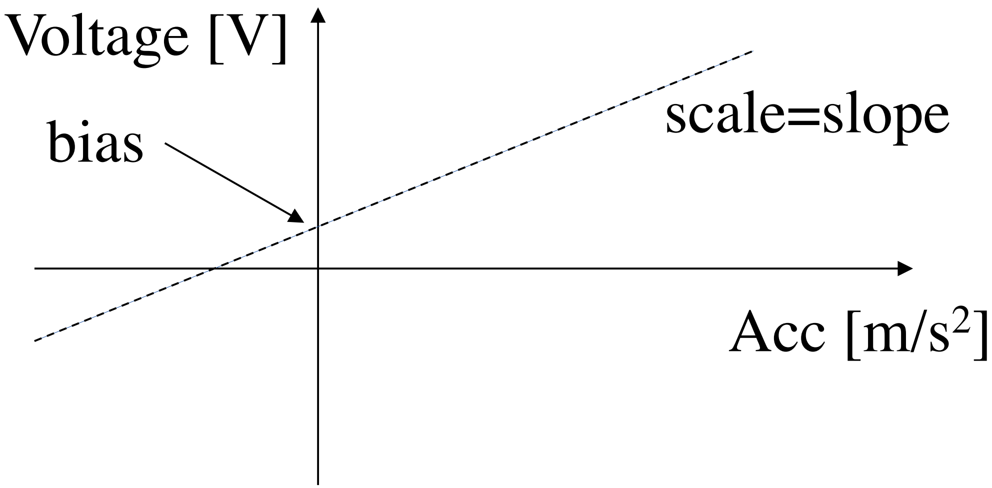
- You typically measure a voltage (e.g. 0-5V)
- Voltage proportional to the quantity in question
- What do you need to know to go from voltage to your quantity?
  - Scale factor for e.g. m/s^2 to voltage
  - Bias (offset) i.e. voltage for 0 output



Acc = (voltage - bias) / scale

Range sensors

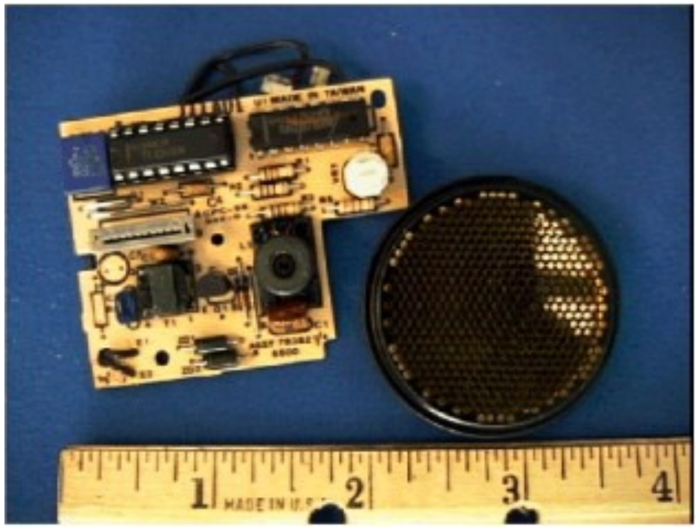
- Several principles
  - Time of flight
  - Triangulation
  - Phase difference
  - Intensity
  - ....

Time of flight (TOF)

- Measure travel time
- Speed of propagation, c, distance d and time t $\rightarrow$ d=ct
- Travels back and forth, i.e. time for two trips $\rightarrow$ d = ct/2
- Speed in air
  - Sound: 344m/s at 20°C
  - Light: 299,792,458 m/s

Ultrasound

- Send out sound pulse and measure time until it comes back (like a bat!)
- Problems?

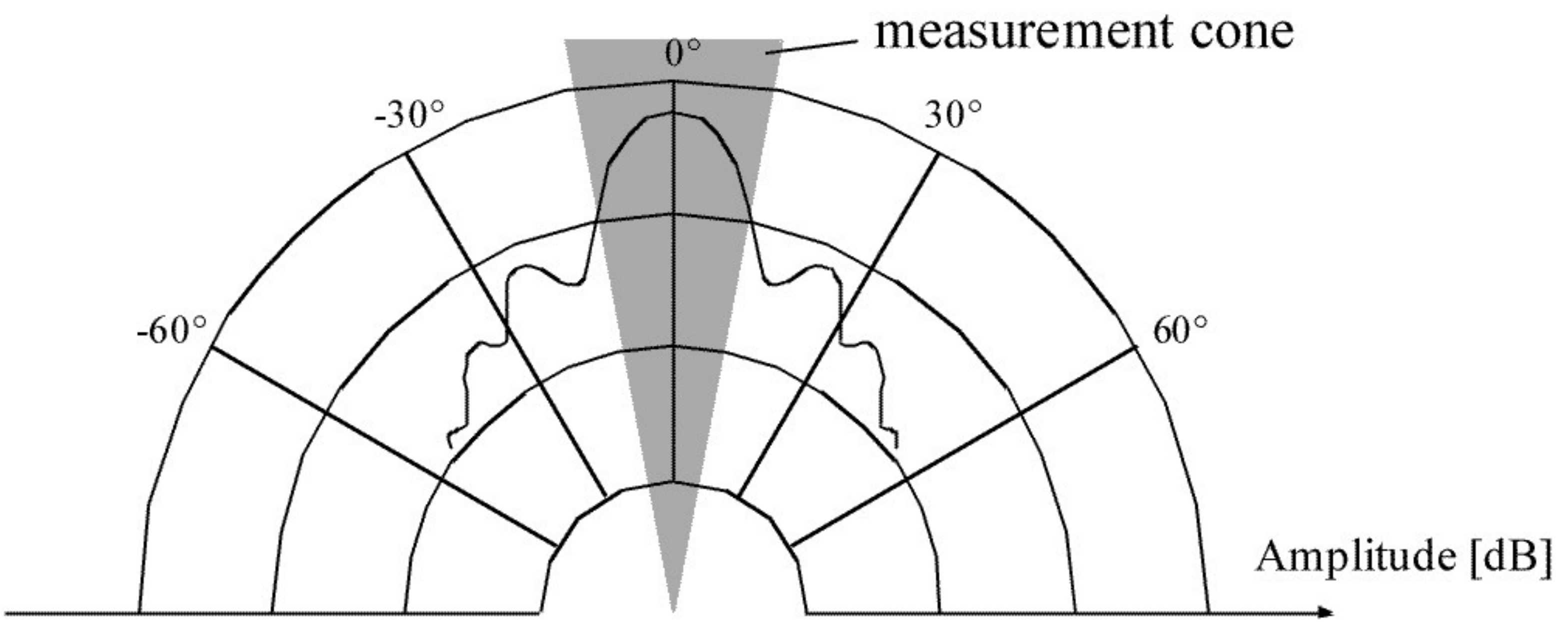


Ultrasound

- Send out sound pulse and measure time until it comes back (like a bat!)
- Problems?
  - Sound is very slow in air (343m/s at 20°C)
    - Low sampling rate
  - Speed temp sensitive (0.6(m/s)/°C)
    - Need to compensate
  - Reflections!!
  - Some materials do not reflect

Sonar ranging

- Typical frequency 40-180kHz
- Sound wave propagates in a cone like manner
- Typically 25-45 degrees opening angle



Example use Sonar

- Parking assistance for cars

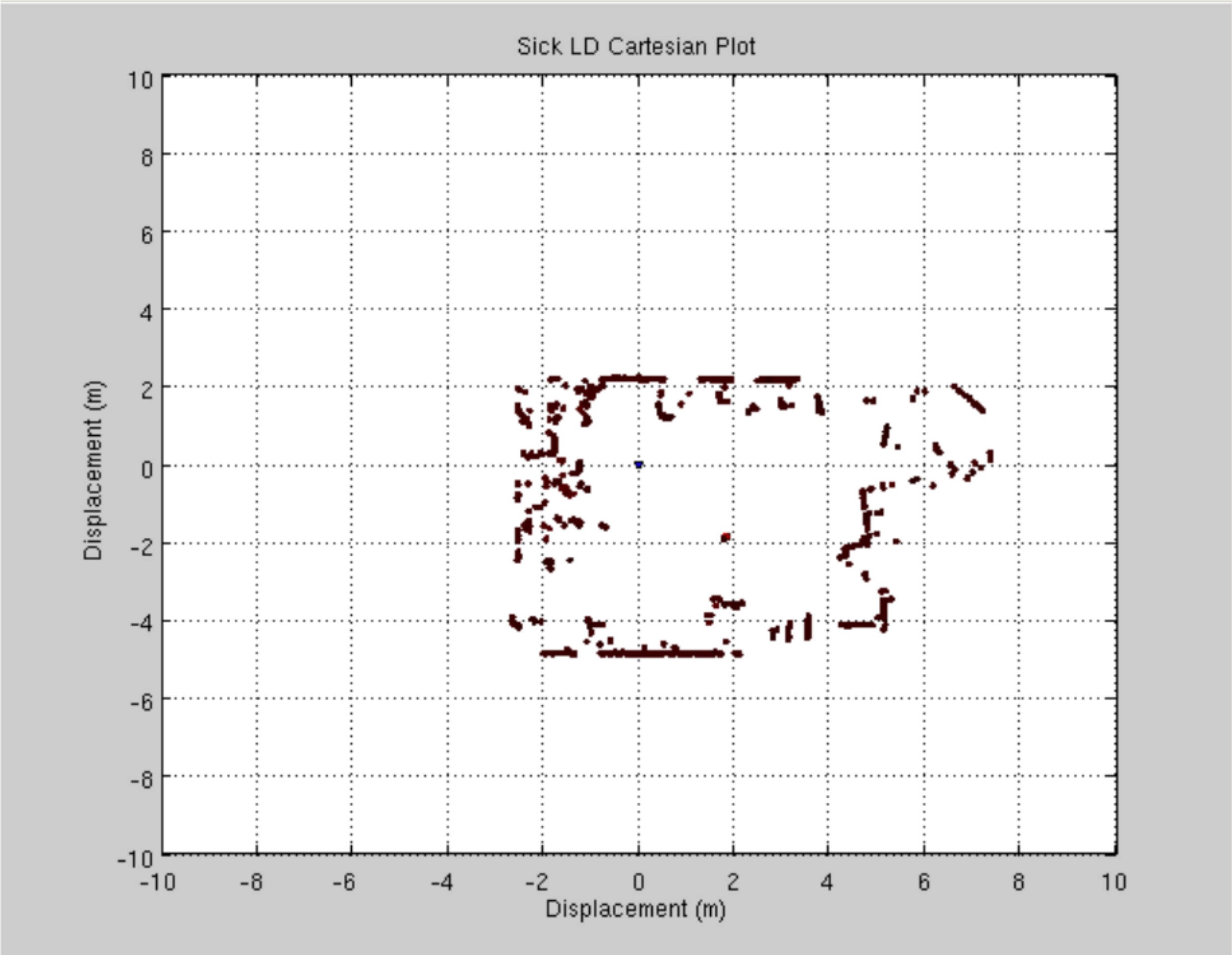
LIDAR

- LIDAR = **Light detection and ranging**

2D version

- Rotating mirror (75Hz)
- Pulsed laser (higher power, less energy)
- Long range (typ 80m) (depends on reflectivity)
- Accuracy 1cm
- Samples with 1°
- Often used in interlaced mode
- (combine two scans shifted 0.5°)
- Safety classified
- Expensive: $4k

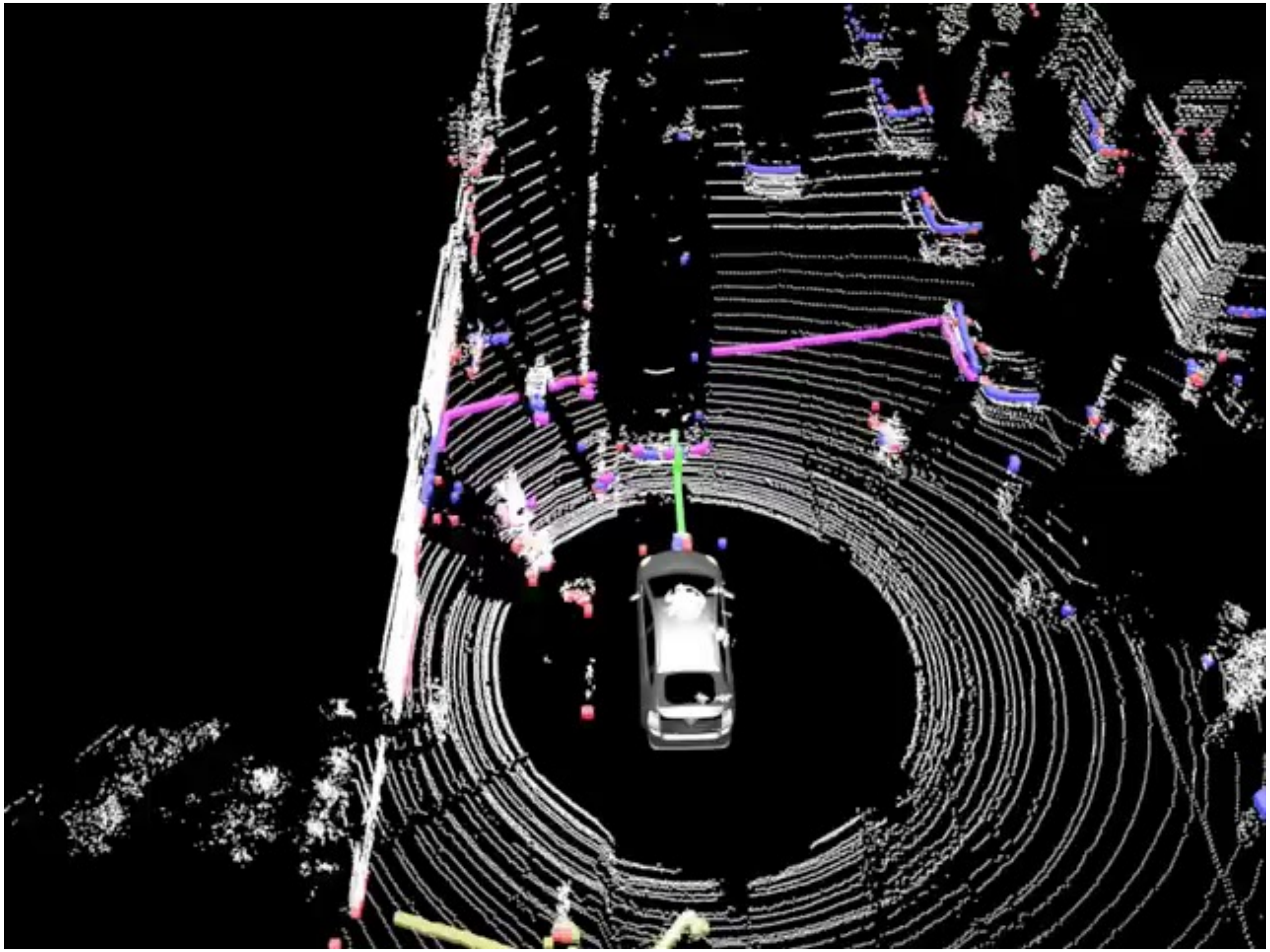
Ex: Laser scanner data



Velodyne 3D laser

Standard autonomous (research) car sensor
16, 32 and 64 scanning beams
Starts at $8000

Example data from 3D laser



Point cloud

The data from a laser (2D or 3D) is often referred to as a point cloud

A modern LiDAR can produce massive amounts of points per second.

Radar

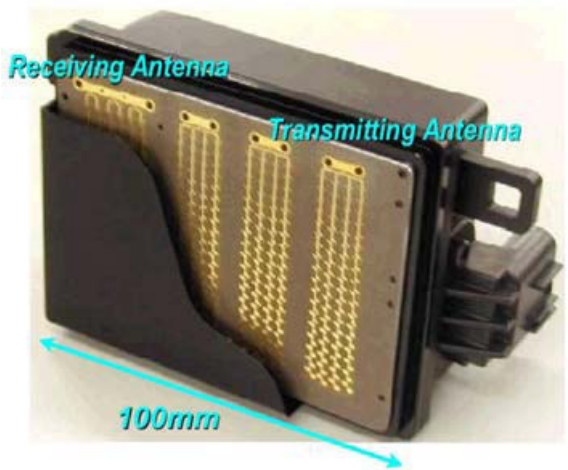
- Radar = **RA**dio **D**etection **A**nd **R**anging

- Transmit and receive radio signal
- Many materials do not absorb / reflect / scatter much of the signal → long range
- High conductivity → strong reflection
- Get range and direction to multiple targets

Applications of radar

- Used heavily in aircrafts and ships industry
- Increasingly in cars and trucks.
  - ACC or autonomous modes

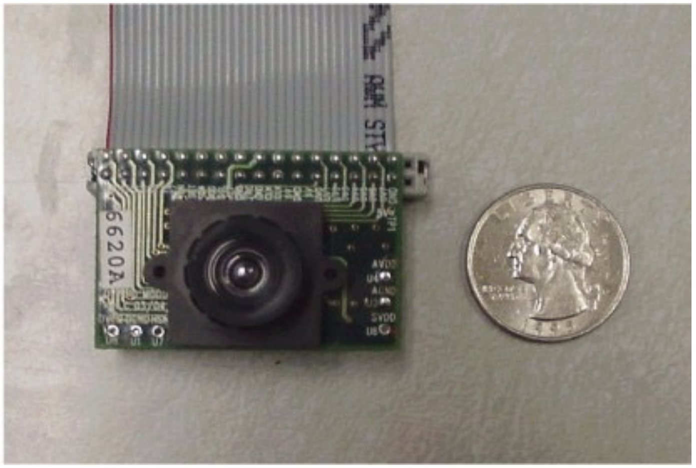
Bosch



Toyota

The camera

- Vision is our (humans) main sensory modality
- Most flexible sensory modality
- Getting the information from the camera data can be very hard
  - Complex sensory processing
- Relatively inexpensive (driven by mass market, mobile phones)



Computer vision

- Making robots see
- A large research field in itself
- There are several courses on image processing and computer vision
  - DD2423, Image Analysis and Computer Vision, per2
  - DD2424, Deep Learning in Data Science, per 4

- Applied computer vision
  - DD2419, Project course in Robotics and Autonomous Systems, per 3-4

Camera calibration

- Need to calibrate your camera just like any other sensor
  - **Intrinsic** camera parameters
    - Describe the “geometry of the camera”
  - **Extrinsic** camera parameters
    - Where is the camera

Intrinsic camera parameters

- Principal point (center of the image) (u_0,v_0)
- Focal length (f) (sometimes f_x, f_y)
- Skew between x and y axes (γ)

A = camera matrix

$$A = \begin{bmatrix} f_x & \gamma & u_0 \\ 0 & f_y & v_0 \\ 0 & 0 & 1 \end{bmatrix}$$

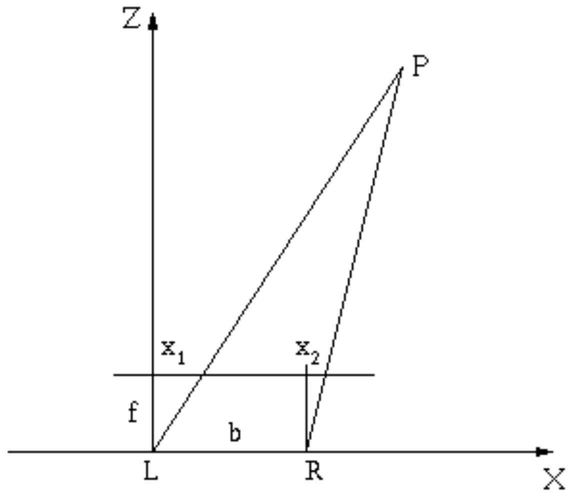
- Lens distortion (non-linear)

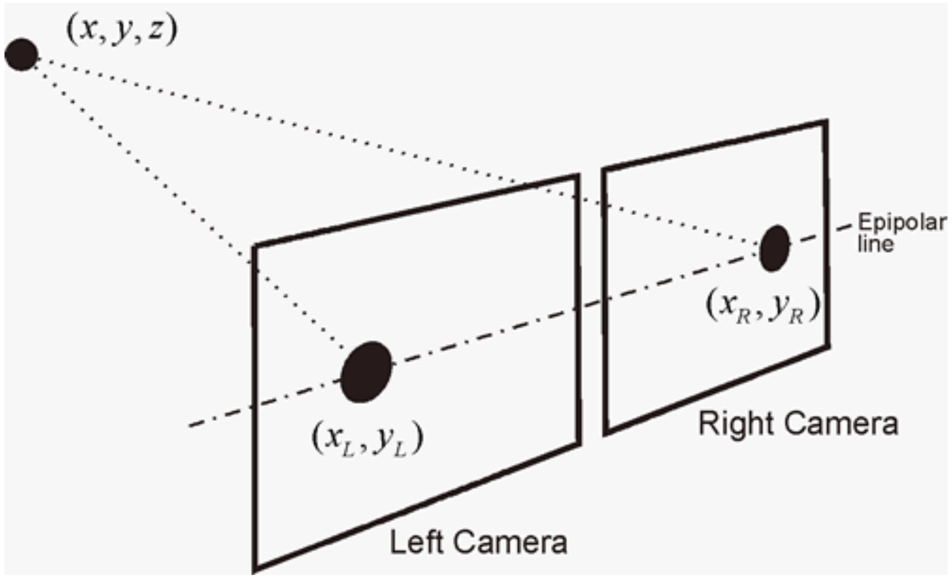
Compensate for distortion

http://www.dxo.com/us/photo/dxo_optics_pro/optics_geometry_corrections/distortion

Stereo vision

- Distance given by baseline, focal length and disparity (difference in image position)
- $Z = b * f / (x_1 - x_2) = b * f / d$





Ex: ZED 2 from Stereolabs

RGB-D camera

- Combines images (RGB) with depth (D)
  - Camera and range sensor in one!!
- Two main techniques
  - Structured light
    - stereo with 1 projector + 1 camera
  - Time of flight (phase shift aka indirect ToF)

Intel RealSense D455

Intel RealSense L515

What does a RGB-D sensor enable?

- Can work directly with geometry
  - You get a point cloud
- Scale is given
  - Not the case for RGB images where scale is unobservable (unless you have something known, stereo baseline, motion between frames, etc)

3D models

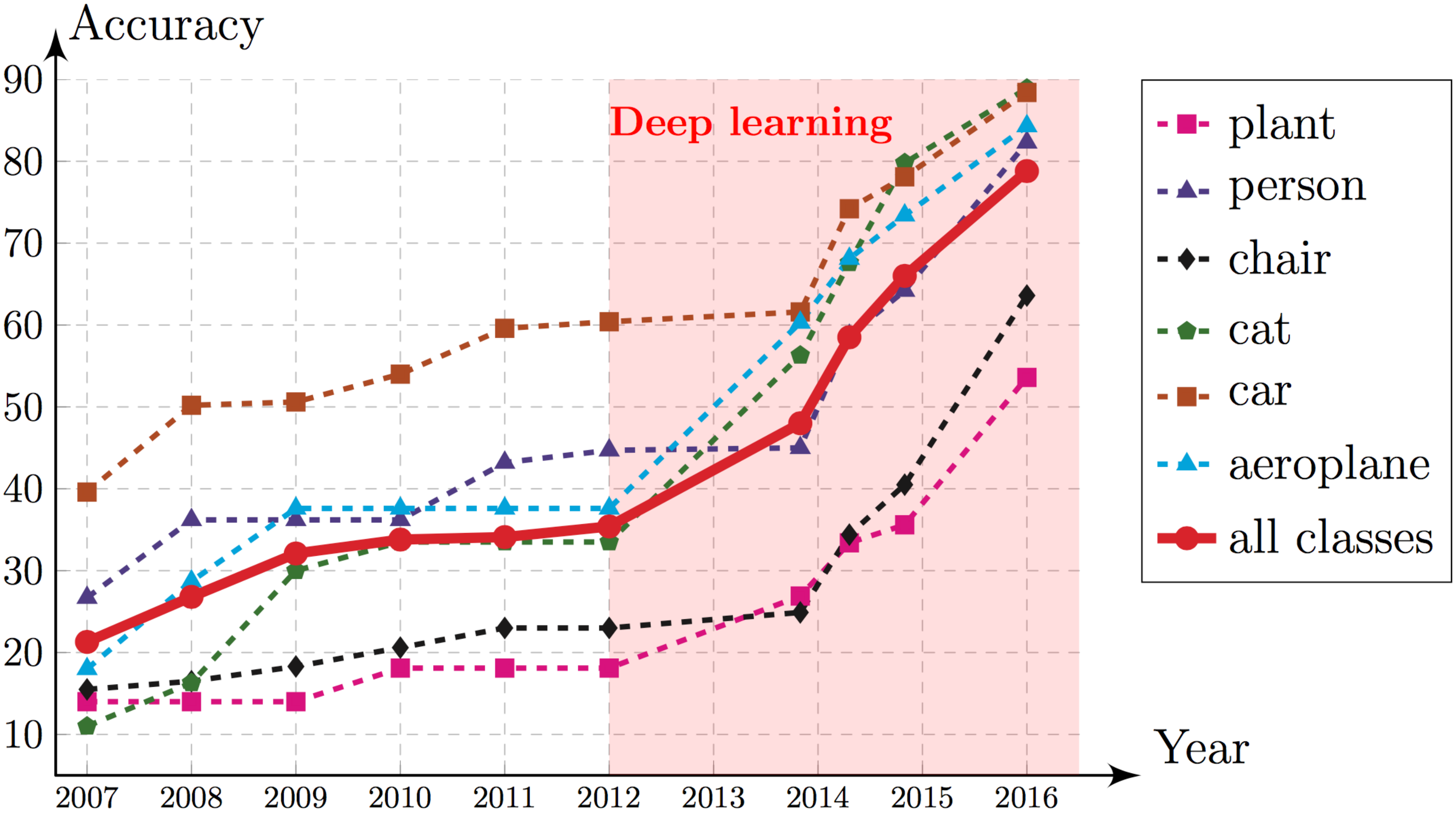
Object recgnition, classificartion, etc

- Long history, slow progress

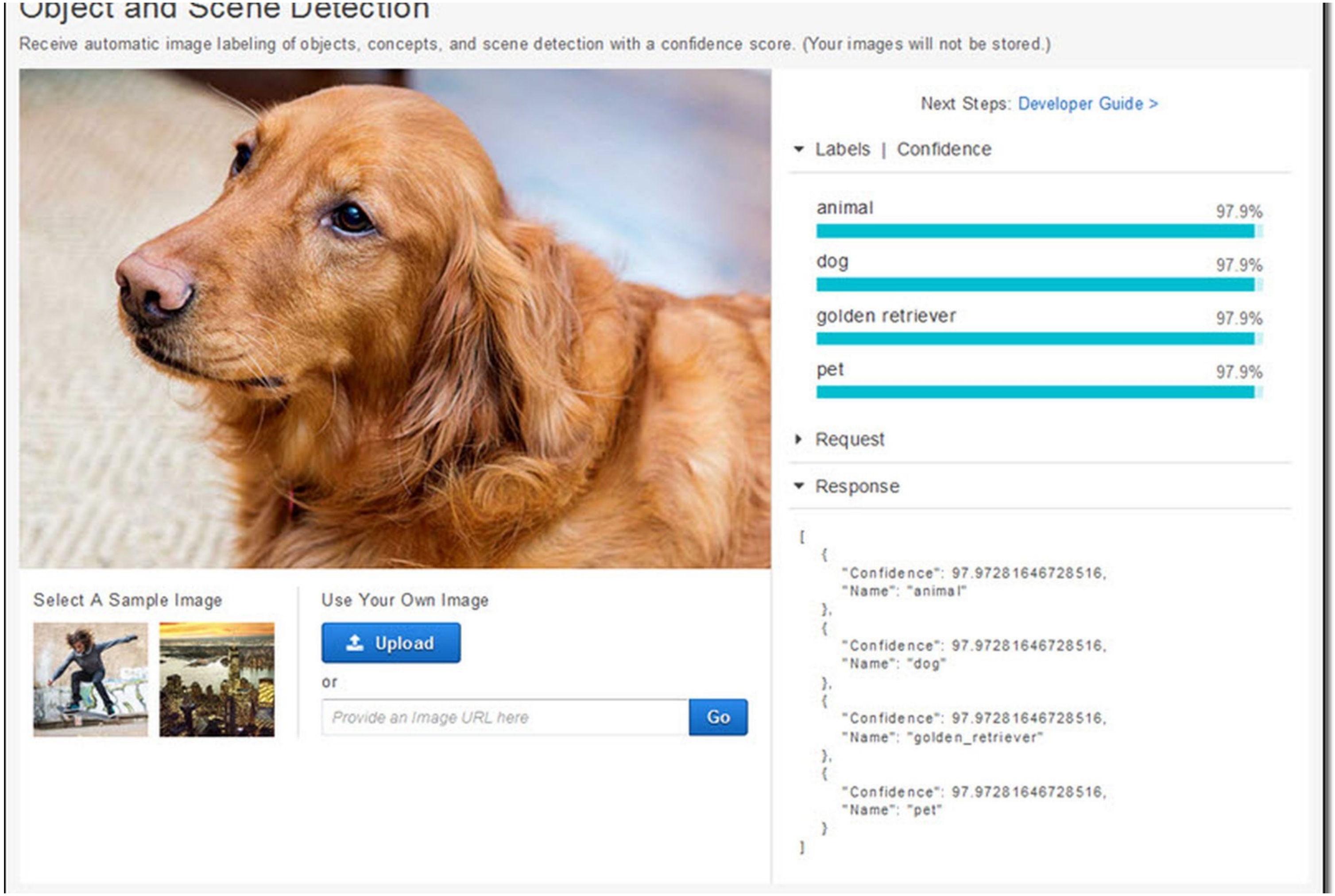
A paradigm shift!

- For a long time, progress was made by coming up with increasingly more complex
  - features
  - classifiers
  - etc
- Then there was deep learning...

Object detection in Pascal VOC 2007 Challenge



Images Understanding



https://www.theverge.com/2016/11/30/13799582/amazon-rekognition-machine-learning-image-processing

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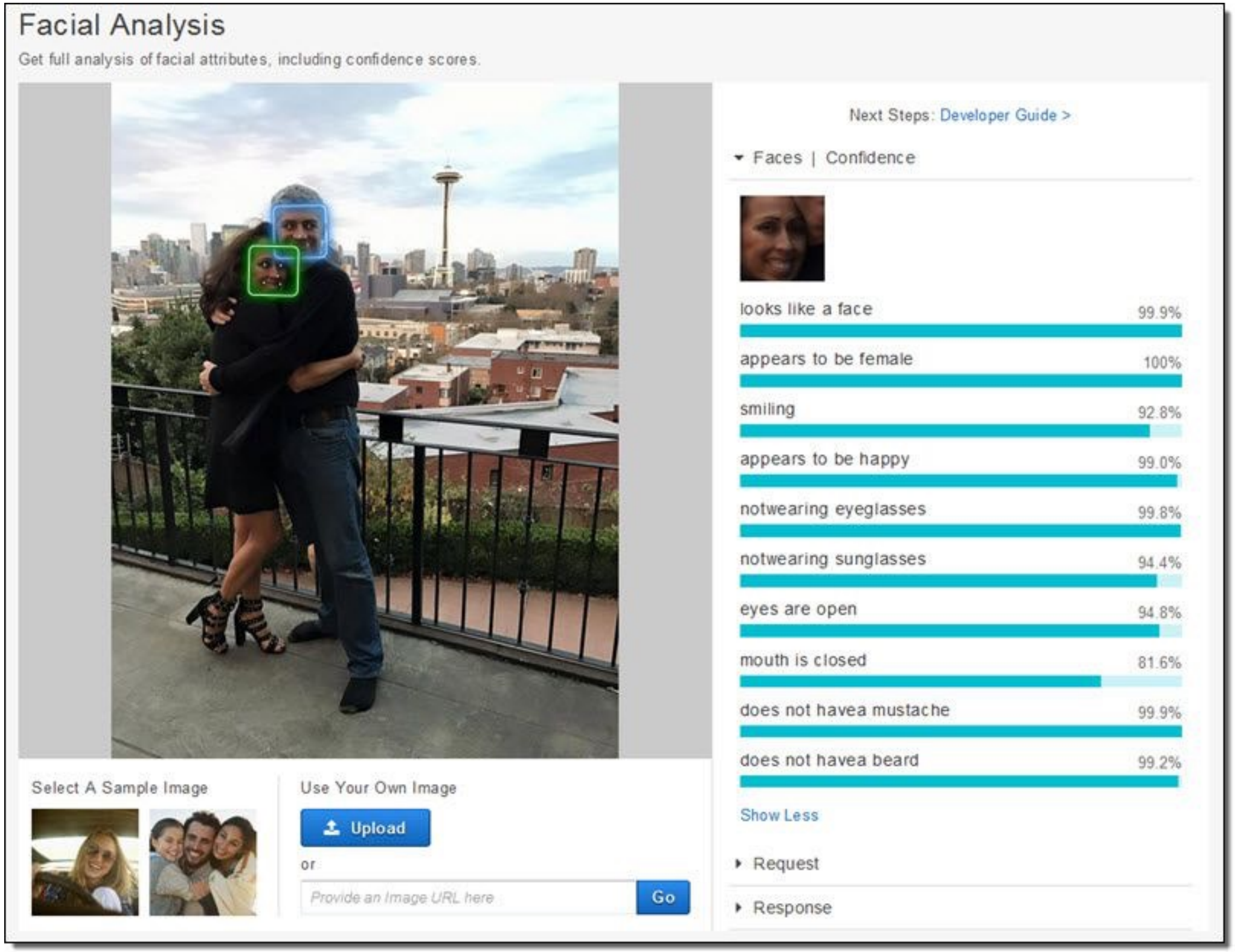

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Learn to infer depth

- Learn to ”see” the depth from a single image (i.e. without stereo)

Ex: “AI mode” in ZED 2