BLG456E
Robotics
Sensing & Sensors

Lecture Contents

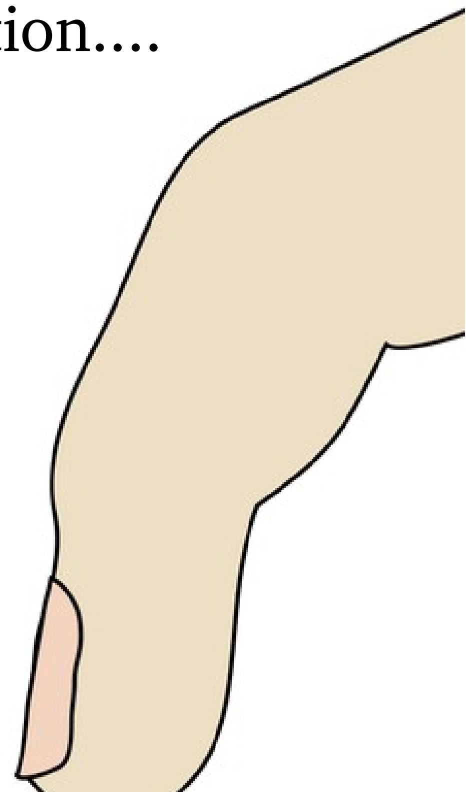
- Robotics is very difficult.
- What is a sensor?
- Sampling basics.
- Sensor properties & noise.
- Sensor case studies.
- Cognitive vs. behavioural approach.
- Robot case studies.

Lecturer: Damien Jade Duff
Email: djduff@itu.edu.tr
Office: EEBF 2316
Schedule: http://djduff.net/my-schedule

Robotics is difficult

- Compare density of touch receptors:
  - One human finger: about 3000 pressure receptors.
    - Also: temperature, pain, motor, sideways motion....
  - Turtlebot:
    - 1 bump sensor (if you are lucky).

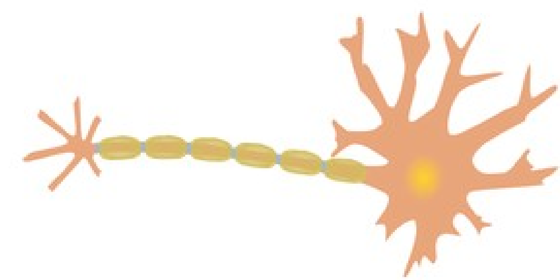
(also smell, vision, hearing, balance...)



https://openclipart.org/detail/21680/sideways-finger-by-ecloud

Robotics is difficult

- Compare density of motor effectors:
  - Every hair on a human body has a muscle.
  - Each capillary has a muscle.
  - At least 500 skeletal muscles.



  - Turtlebot: two wheel motors.

Robotics is difficult

- More reasons:
  - State is **partially observable**.
  - Environments are **unpredictable**.
  - Environments are **dynamic**.

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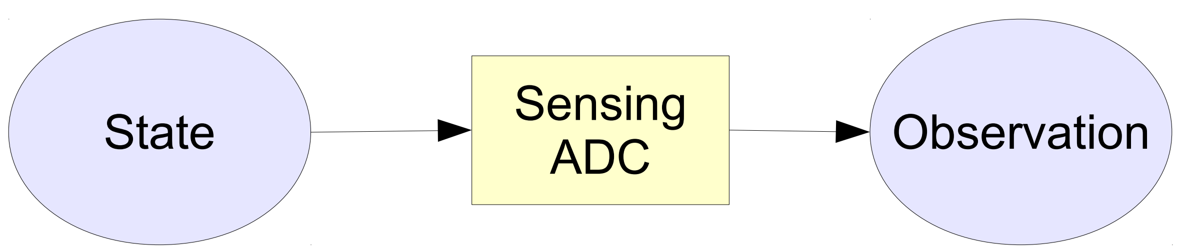
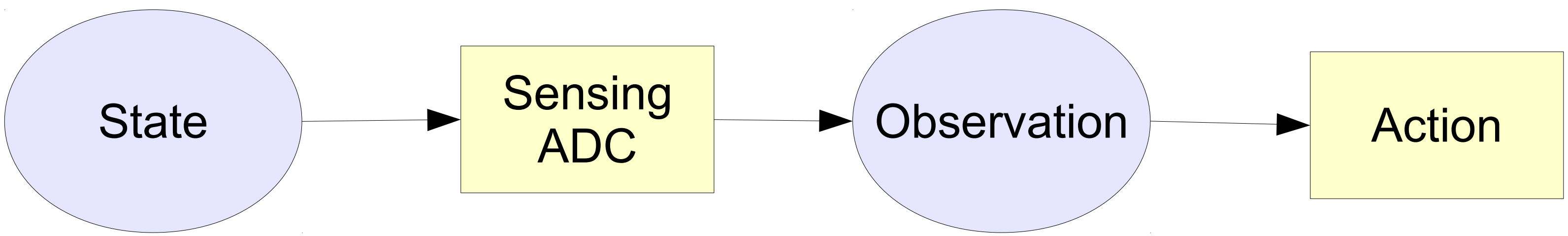
What is a sensor

- External interface to perceptual system.
- Physical device, measure physical quantities.
    - light travel time → current → voltage → sample.
- Does not measure **state** of outside world.
    - Creates **observations**.

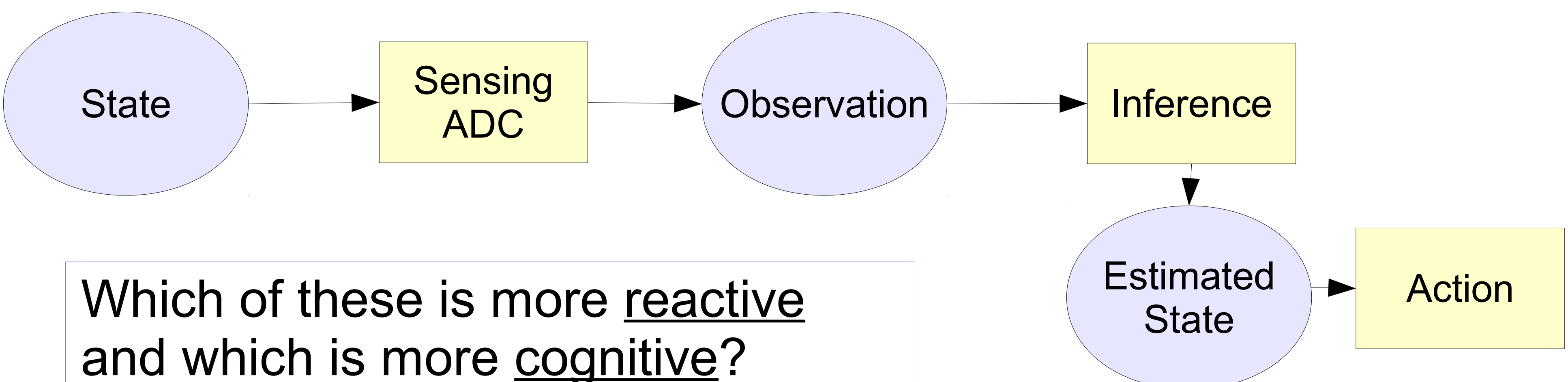


What is a sensor for?

- Determining best action:



- Determining current world-state:



Which of these is more <u>reactive</u> and which is more <u>cognitive</u>?

Examples of sensors

Measured entity	Sensor
Contact	Switch
Distance	Ultrasound, infrared, radar (passive vision)
Magnetic field	Compass
Light level	Photocells, cameras
Sound	Microphone
Strain	Strain gauge
Rotation	Encoders, switch
Temperature	Thermometer
Gravity	Inclinometer
Orientation	Gyroscope
Acceleration	Accelerometer
Fire	UV detector

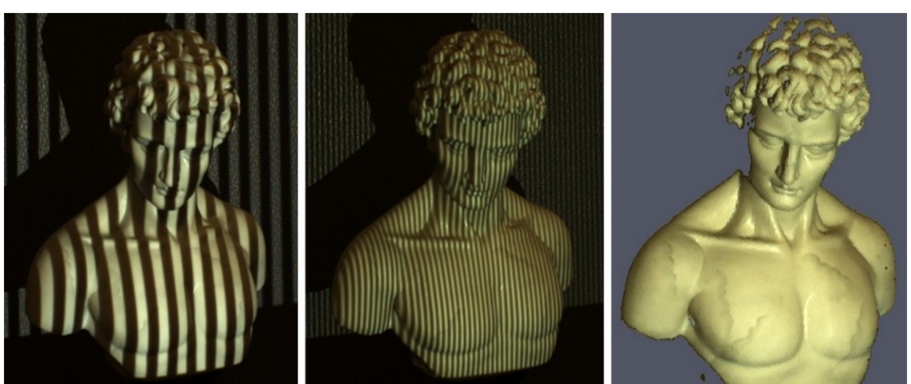
Categorisations of sensors

Energy source:

- Passive: receive energy only.
  - e.g. vision, hearing.
- Active: emit energy.
  - e.g. radar, structured light.

Information source:

- Proprioceptive: internal properties.
  - e.g. joint torque, battery level.
- Exteroceptive: external properties.
  - e.g. radar, vision.



Structured Light

Image from http://mesh.brown.edu/3dpgp-2009

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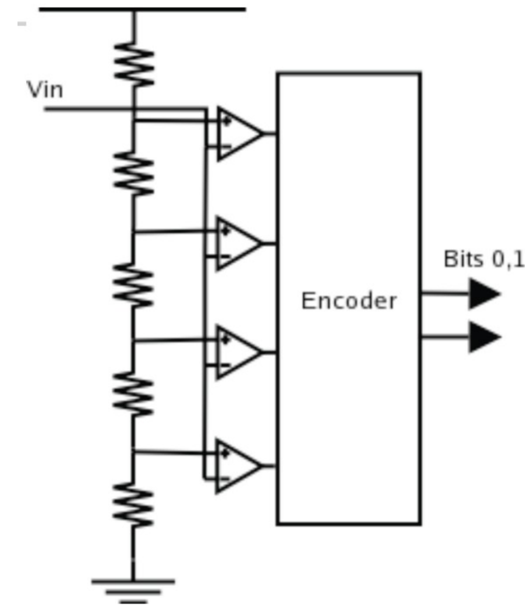
Sampling a signal

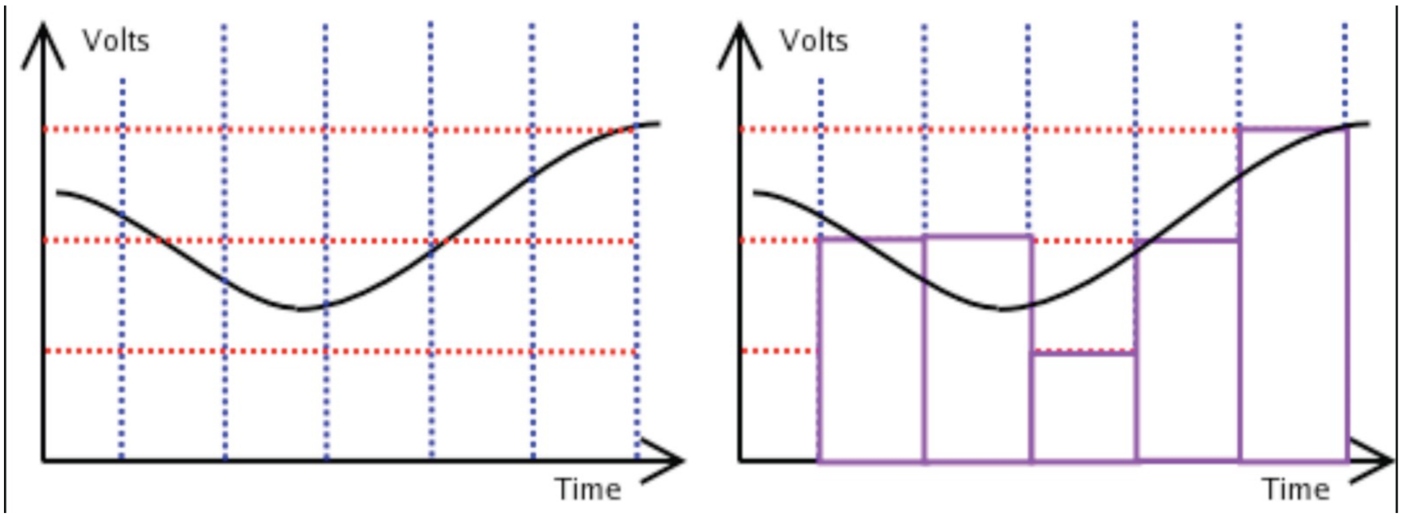


Analogue to Digital Conversion (ADC).

- Specialised circuits.
- Often: analogue comparators.

Sampling time-varying waveform:

- Resolution (y axis).
- Frequency (x axis).



Sensor system design

- Design criteria:
  - Task.
  - Environment.
  - Available sensors.
  - Sensor placement locations.
  - Sensor use possibilities.
- Principle 1:
  - Required actions → sensors.
- Principle 2:
  - Robustness, new situations.

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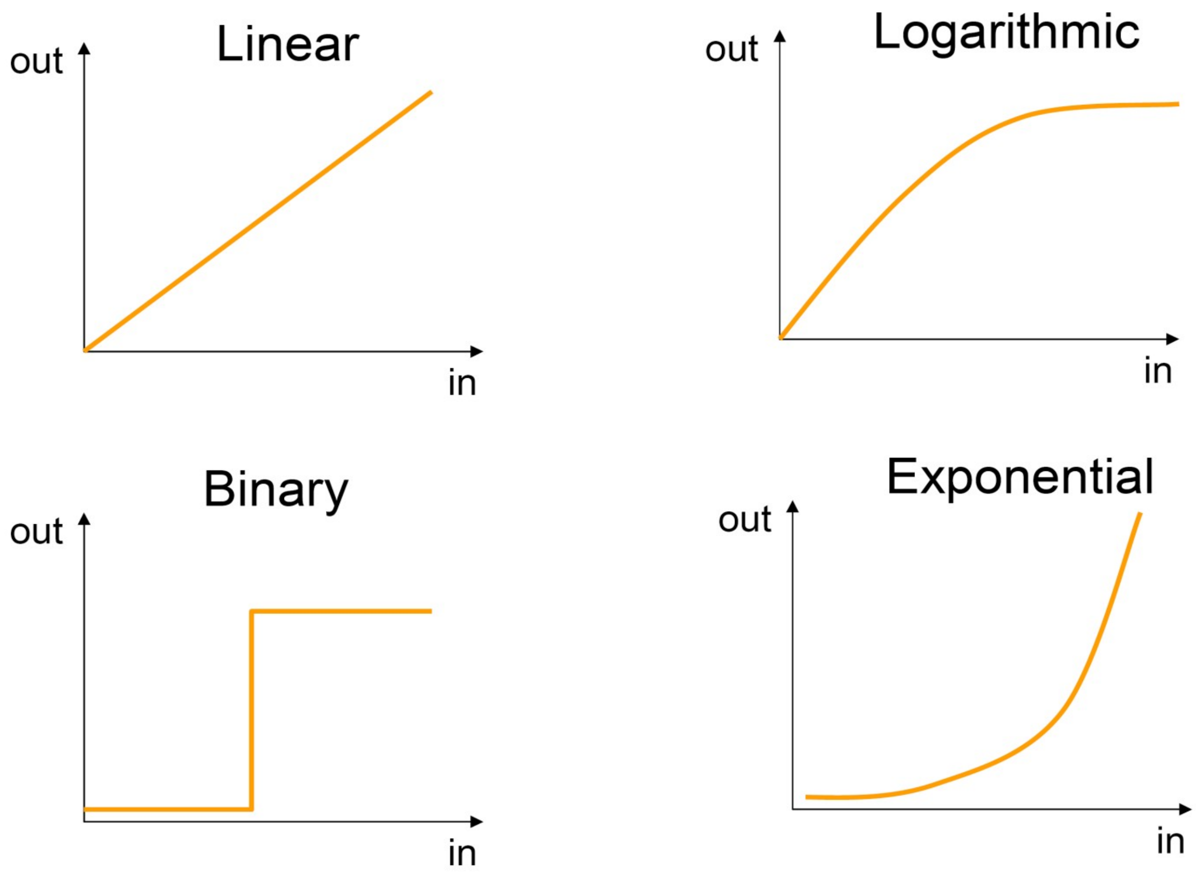
Sensor properties

- Working input range.
  - e.g. thermometer -5°C to 30°.
- Output range.
  - e.g. 0V to 5V.
- Sensitivity (input vs output slope).
  - e.g. 0.15V per 1°C.
- Latency.
  - e.g. 14s to detect 1°C change.
- Stability.
  - e.g. thermal noise, radiation affecting circuits, air pressure.

Operating regimes

- Output-input functional relationships.



Common in animals.

Soft signals: sensitive.
Strong signals: insensitive.

Signal & Noise

- Signal: object-related info.
  - e.g. speech, object-related, environment related.
- Noise: obscuring info.
  - e.g. ambient noise, electromagnetic radiation, static noise.

- Ideal sensor: $r = f_S(s)$
- Sensor with additive noise: $r = f_S(s) + \eta$
- Sensor with non-additive noise: $r = f_S(s, \eta)$

s : signal
η : noise
r : response

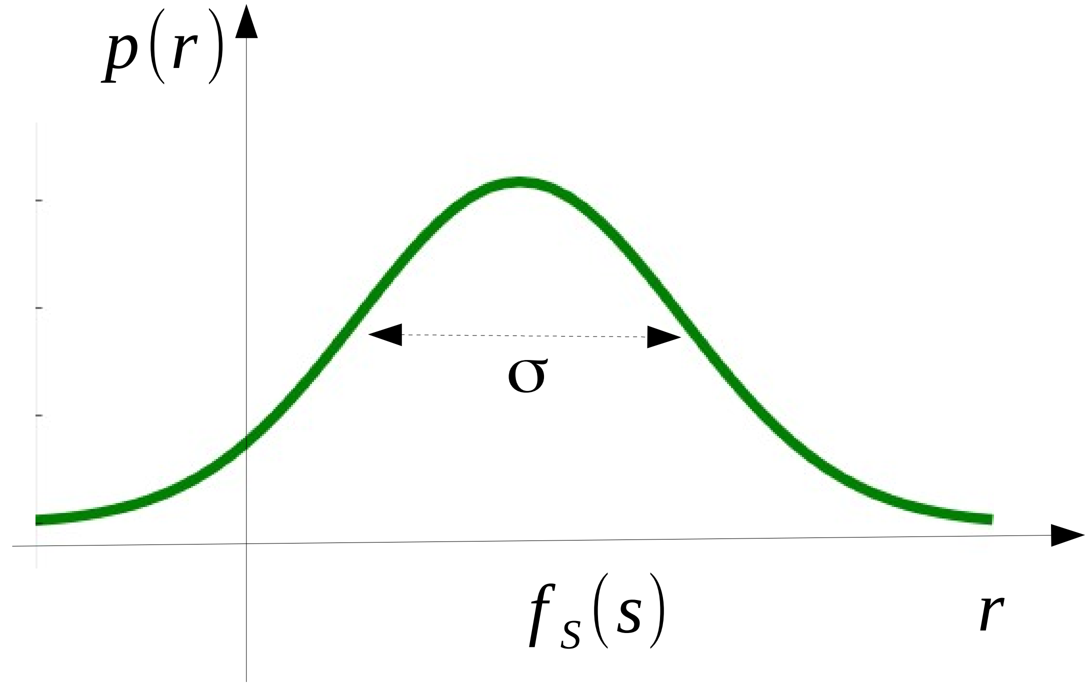
Noise models

- If simple noise model, can estimate.
- E.g. additive unbiased normal:

$$r = f_S(s) + \eta$$

$$\eta \sim N[0, \sigma^2]$$

$$p(r) = \frac{1}{\sqrt{2\pi\sigma^2}} e^{\frac{-(r - f_S(s))^2}{2\sigma^2}}$$



Ways to defeat noise

- Sensor calibration.
  - Creating a noise model.
    - e.g. constant weight bias in a scale.
    - e.g. background hiss in microphone.
- Shielding & structured environments.
- Sensor fusion.
- Active sensing.

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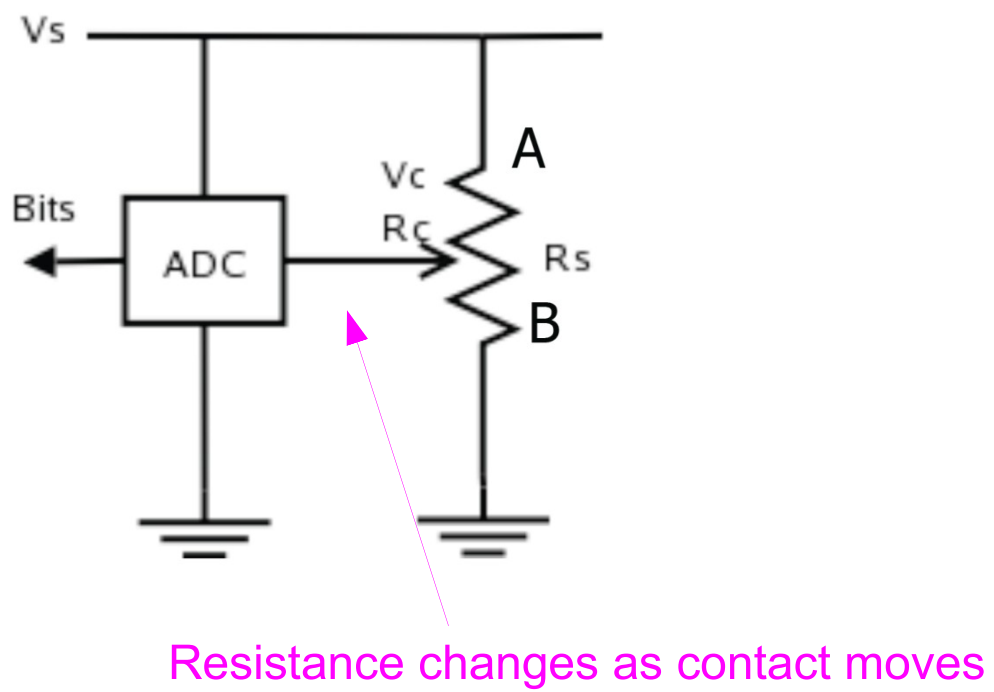
Sensor case study: Switches

- 1-bit signal.
- Types:
  - Normally open (circuit).
  - Normally closed (circuit).
- Uses:
  - Contact trigger ("bump").
  - Limit trigger.
  - Shaft encoder (odometry).
  - Tilt detection (using e.g. mercury).

Sensor case study: Potentiometer

- Resistance varied continuously with movement.
  - e.g. volume knob.
  - e.g. rotation in joint.



Sensor case study: Photocells

Two main types:

- Photoresistor: light-dependent resistor.
  - More light → More resistance.

$$V+ = I\ (R1 + R2)$$

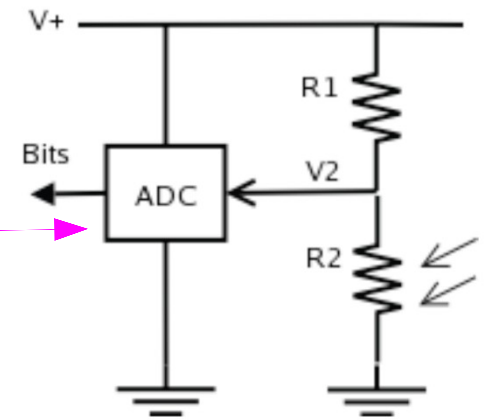
$$I = \frac{V+}{R1 + R2}$$

$$V2 = I\ R2$$

$$V2 = \frac{R2\ V+}{R1 + R2}$$

ADC measures voltage

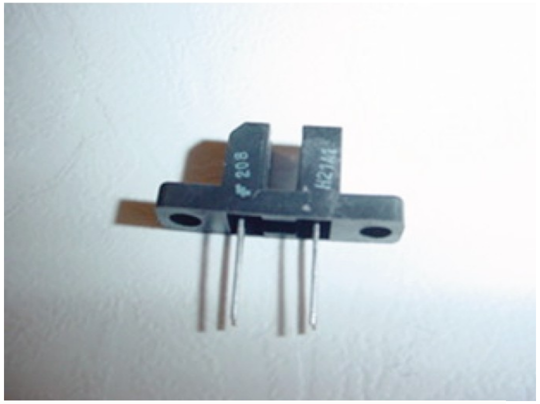
Resistance determined by light

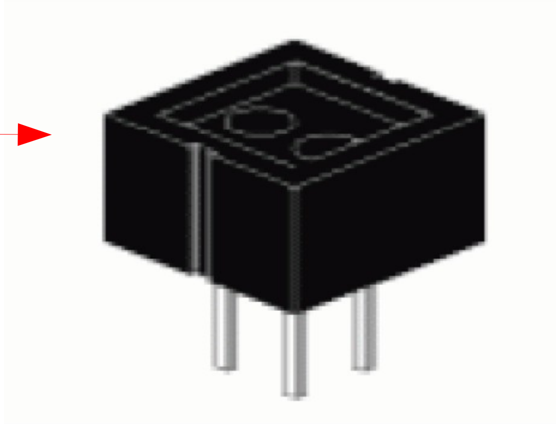


- Photodiode: light-dependent diode.
  - More light → More current.

Sensor case study: Optosensors

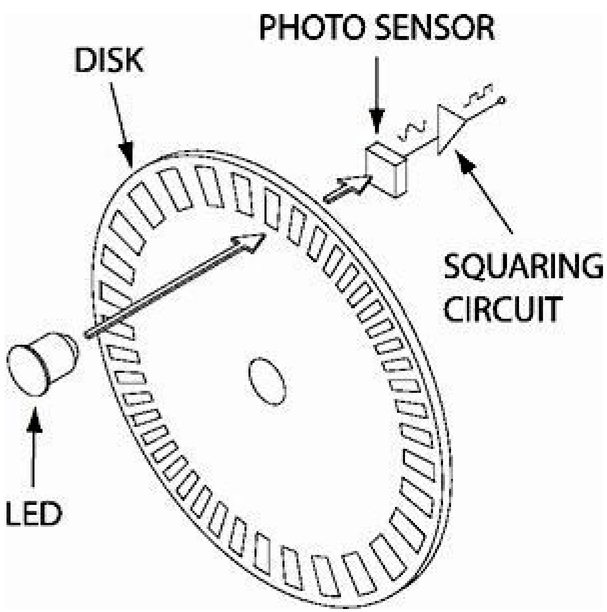
- Emitter/detector pair.
  - LED + photoresister/photodiode.
  - Matched wavelengths (usually IR).
- Configurations:
  - Breakbeam.
    - Detect object between.
  - Reflective.
    - Detect nearby reflective objects.

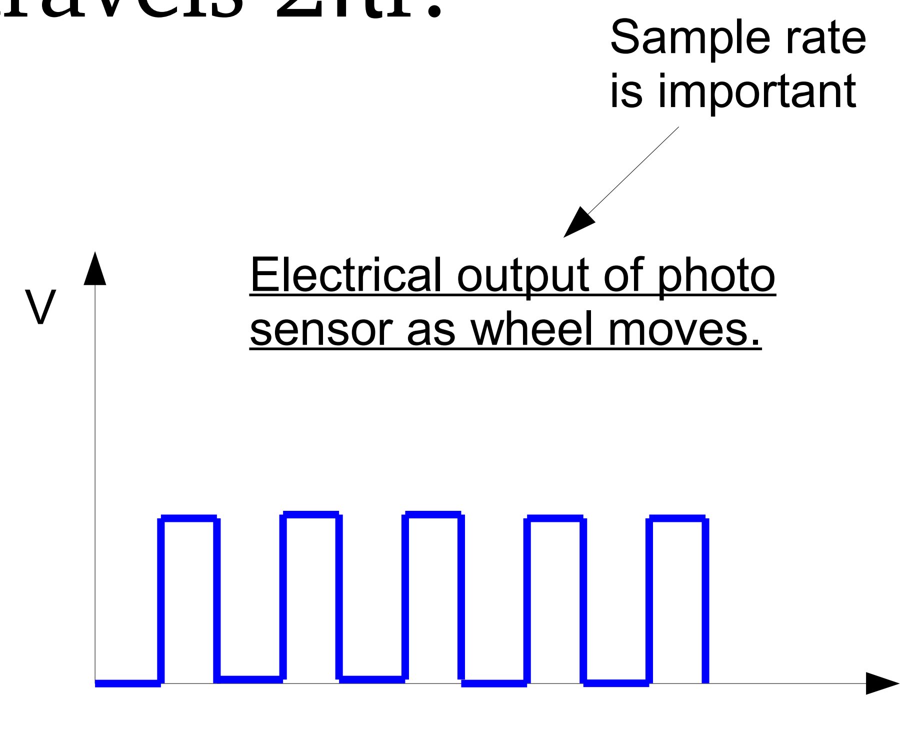




Odometry Computation
(using optical encoders)

- Pulses per revolution = num holes.
- Each turn of wheel travels $2\pi r$.

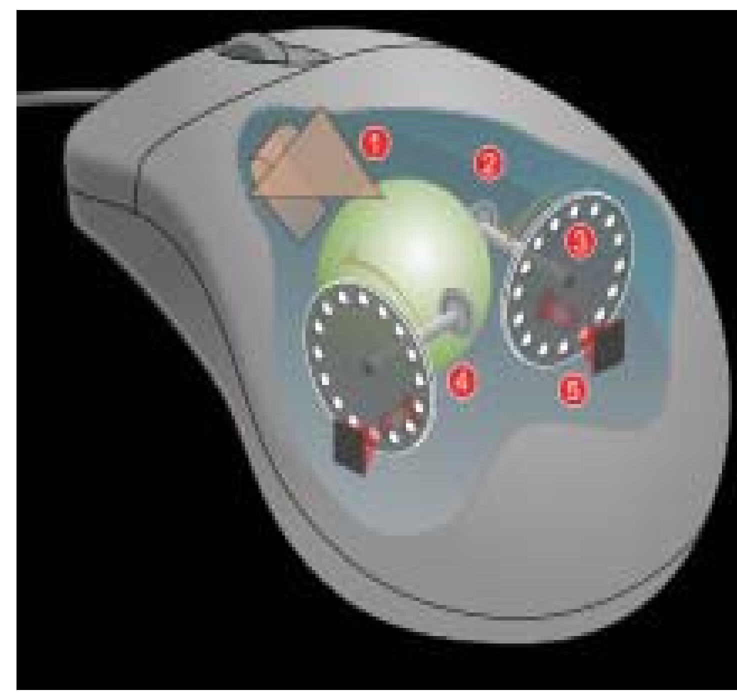




Exercise: A wheel of radius 0.5m has 40 holes and the photo sensor pulses 20 times. How much has it turned (in radians)?

Exercise: How far has it travelled?

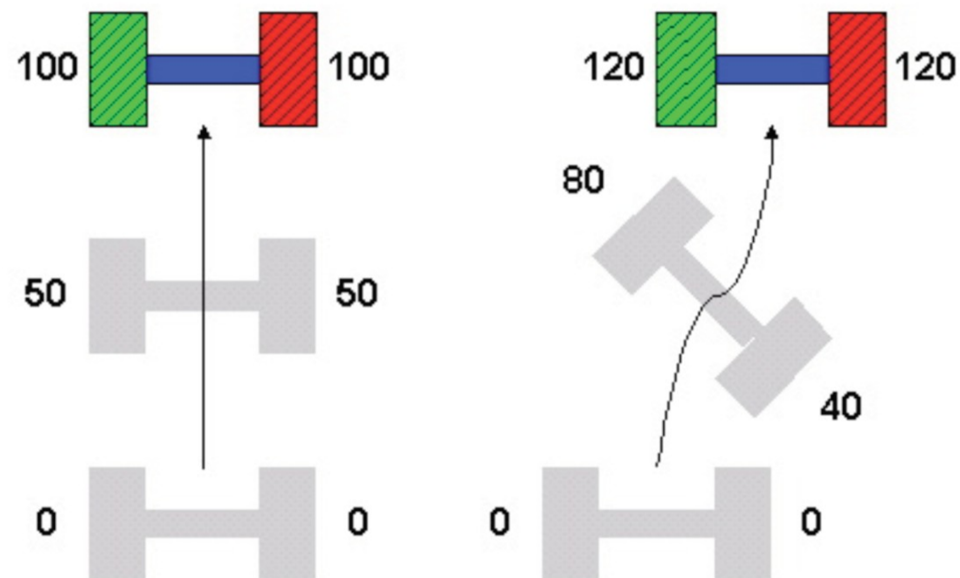
Uses of Encoders



When odometry goes wrong

- Lateral slip.
- Skidding.
- Pulse counting errors.
  - Slow ADC.
    (analog-digital conversion)
- Slow integration.
- Measurement errors:
  - Inaccurate wheel diameter.
  - Wear.

Slow integration.

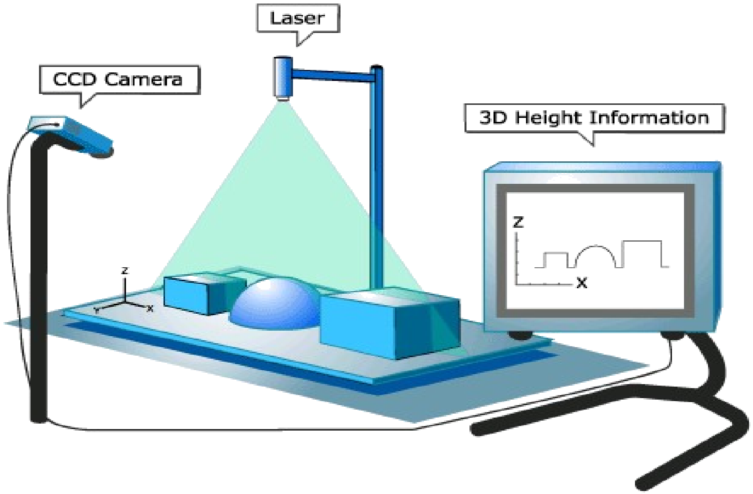


Common Range Sensors

- Sonar/ultrasound.

- Laser range finder.

- Time of Flight & Depth Cameras.



- Structured light.

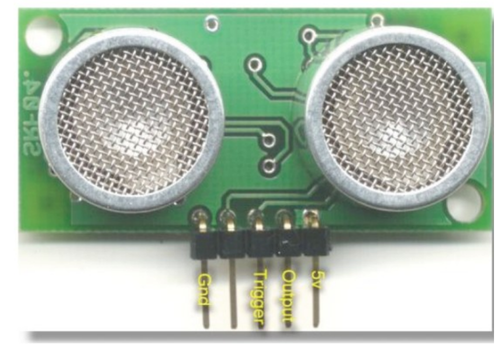
Sensor case study: Ultrasound

- Time-of-flight (TOF) principle.

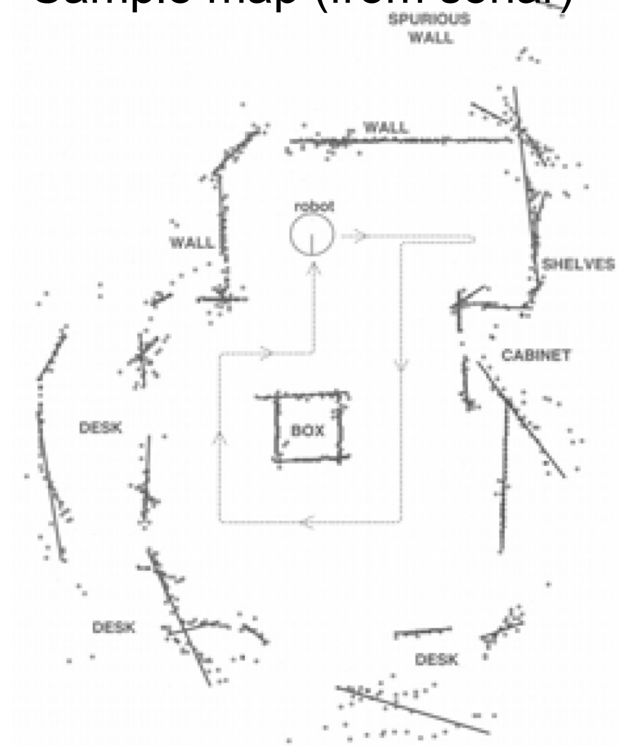
  (also used by radar, laser range-finding, time of flight cameras)

- Process:
  - Emitter: emit chirp.
  - Detector: receive chirp.
  - Calculate distance from TOF.
    - Speed of sound ~ 330 ms^{-1} (air).
  - Repeat.

Emitter Detector

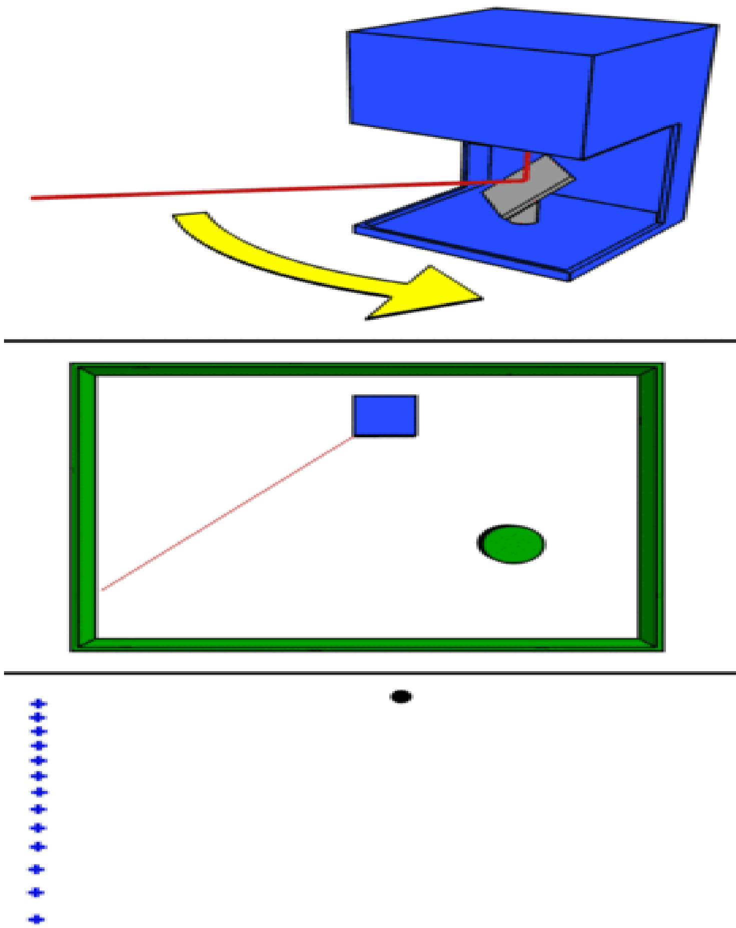


Sample map (from sonar)



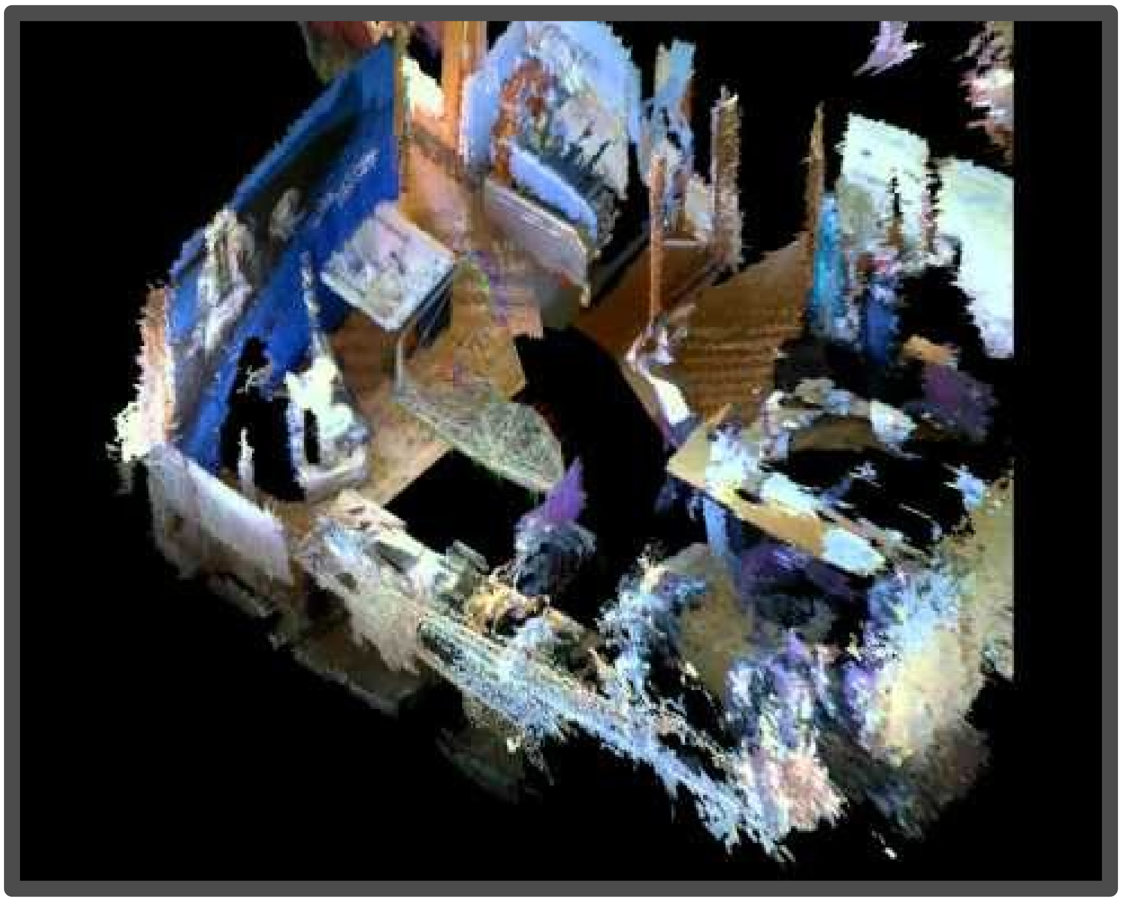
Sensor case study: Laser scanning/lidar

- LIght Detection And Ranging.
- Speed of light ~ 300 million ms^{-1}.
  - Fast.
  - High resolution.
- Scanning: rotating mirrors: 2D/3D.
- Point or 1D collector arrays.



https://www.rudi.net/node/20641

Sensor case-study: RGBD sensor (ASUS Xtion Pro Live)

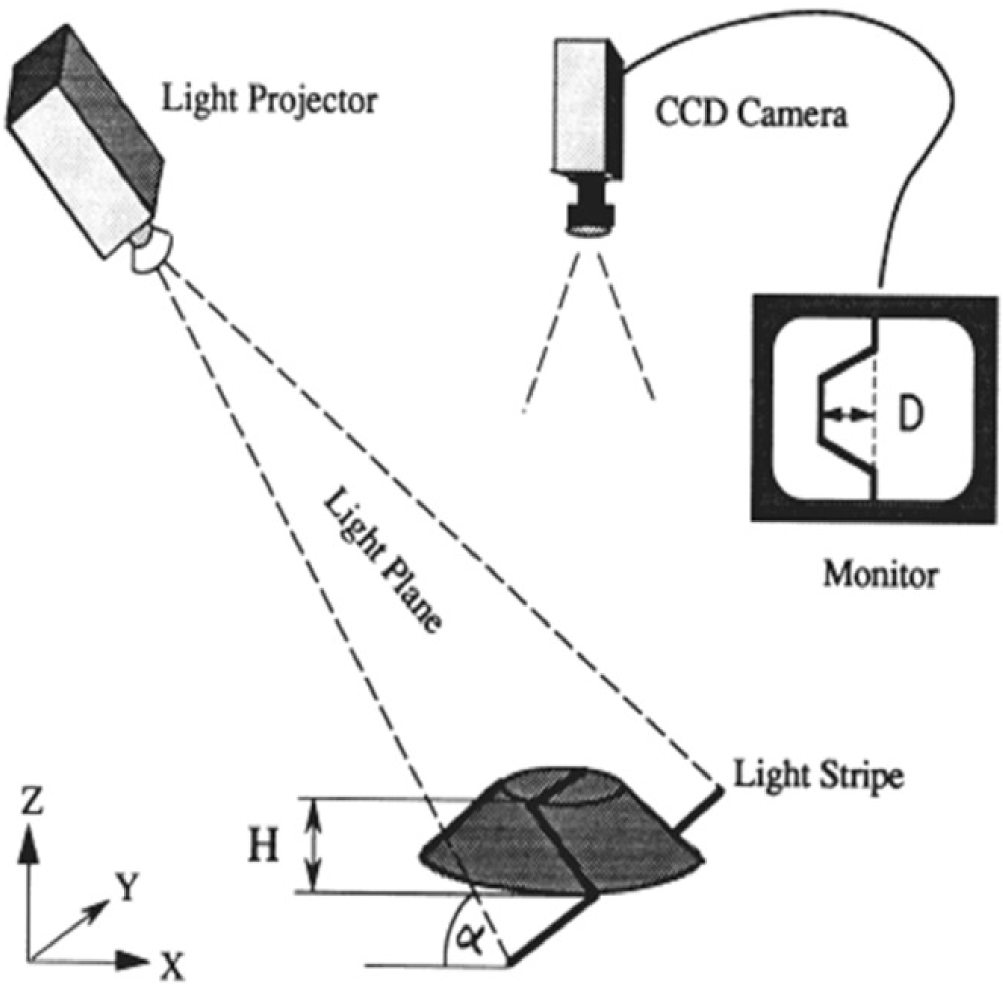


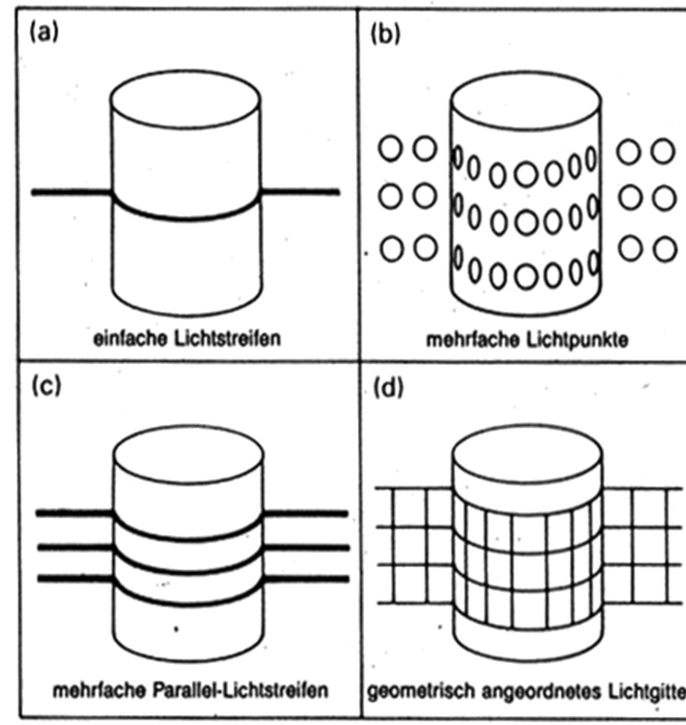
Uses structured light (infrared).

- TOF cameras also available with similar qualities.

(also demo RGBD-SLAM from Freiburg)

Structured Light





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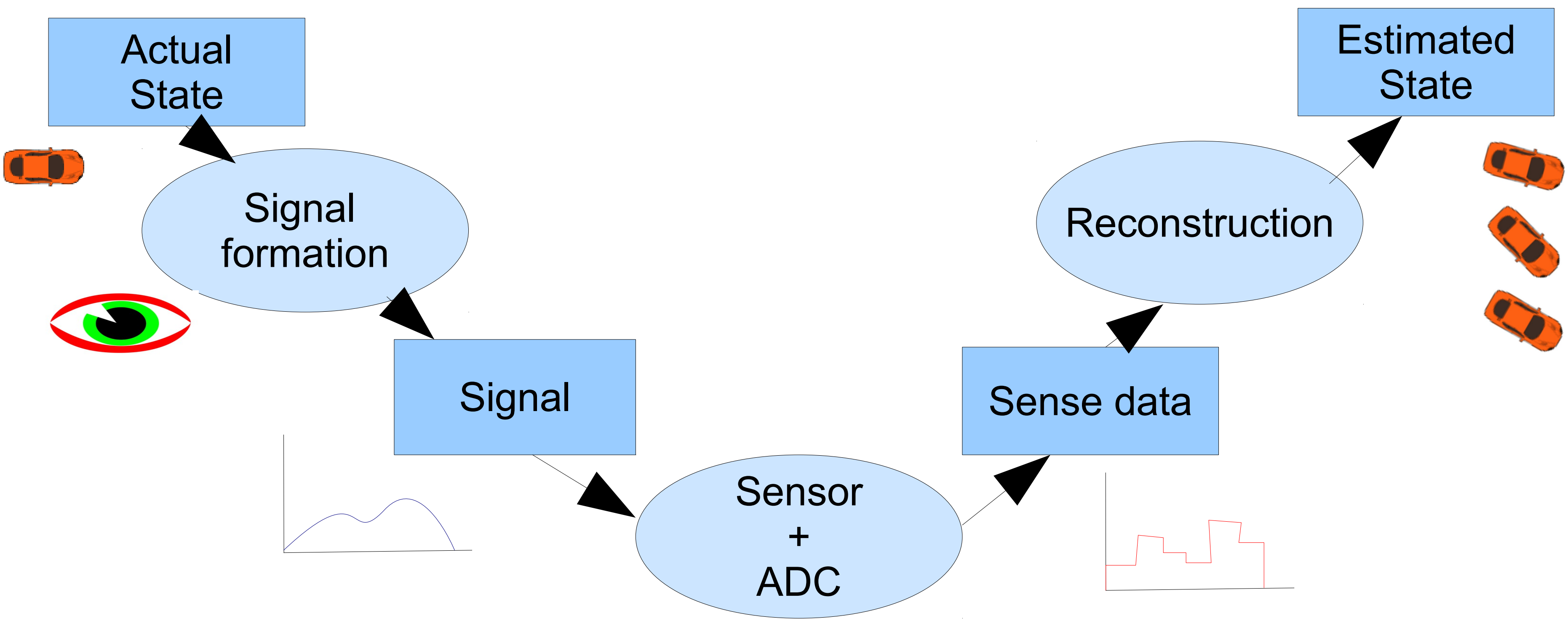
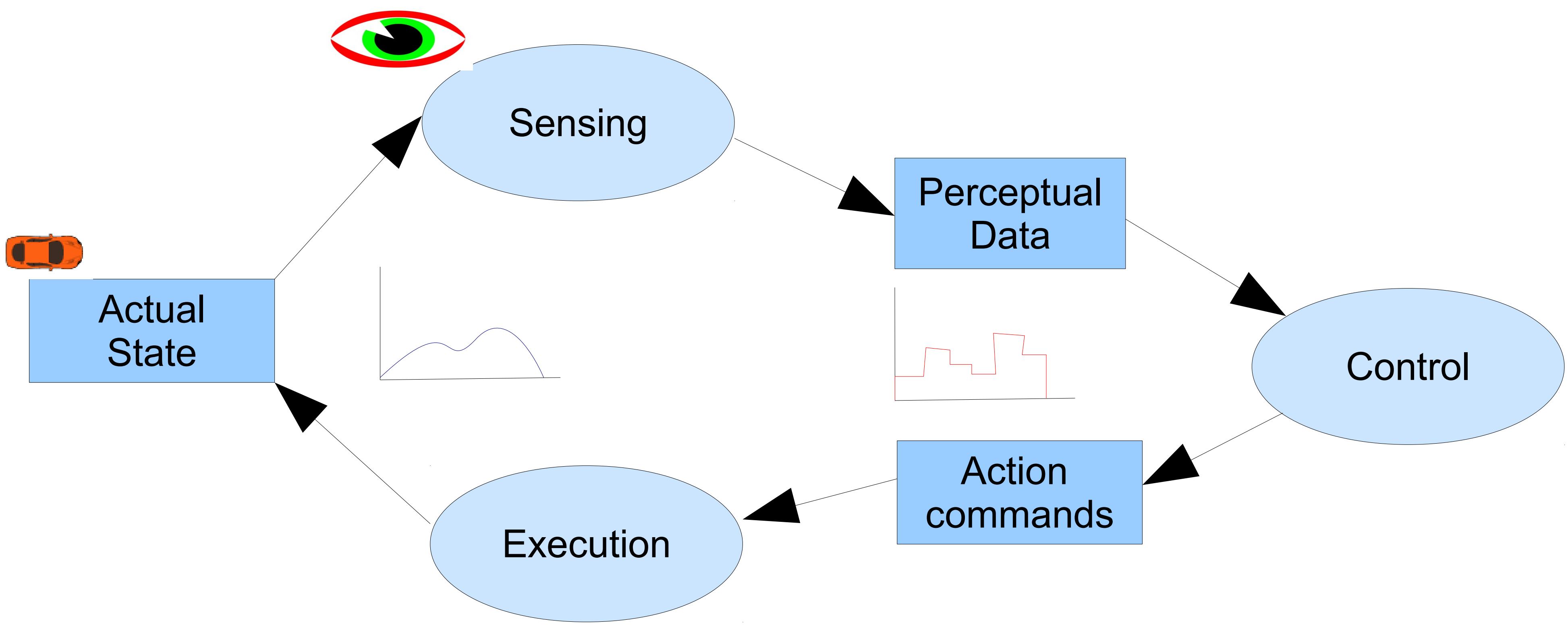
Cognitive approach: Reconstruction from sense data

"What must the world be like to get these readings?"



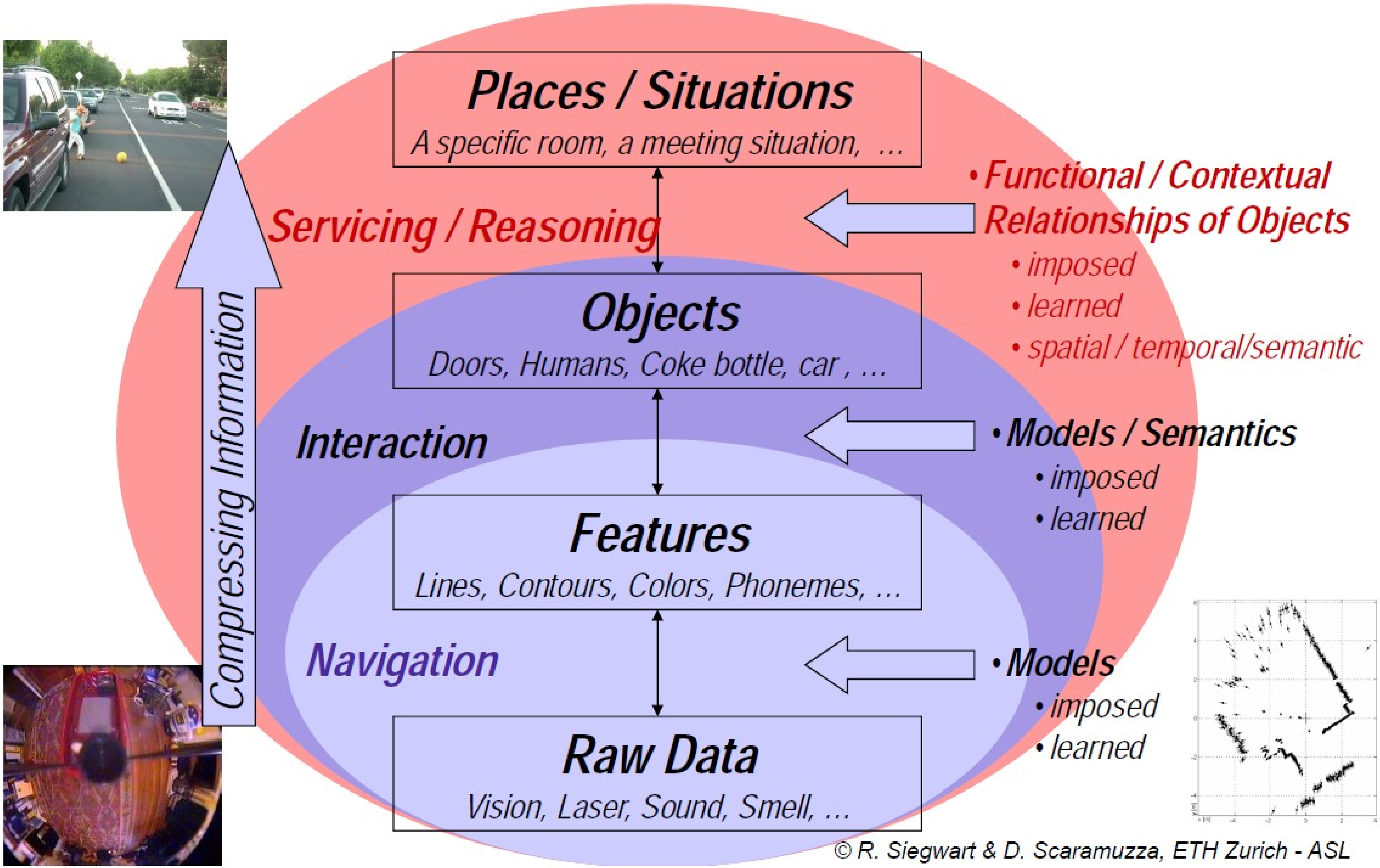
Behavioural approach: Sense-action mapping

"What behaviour is necessary to get desired result?"

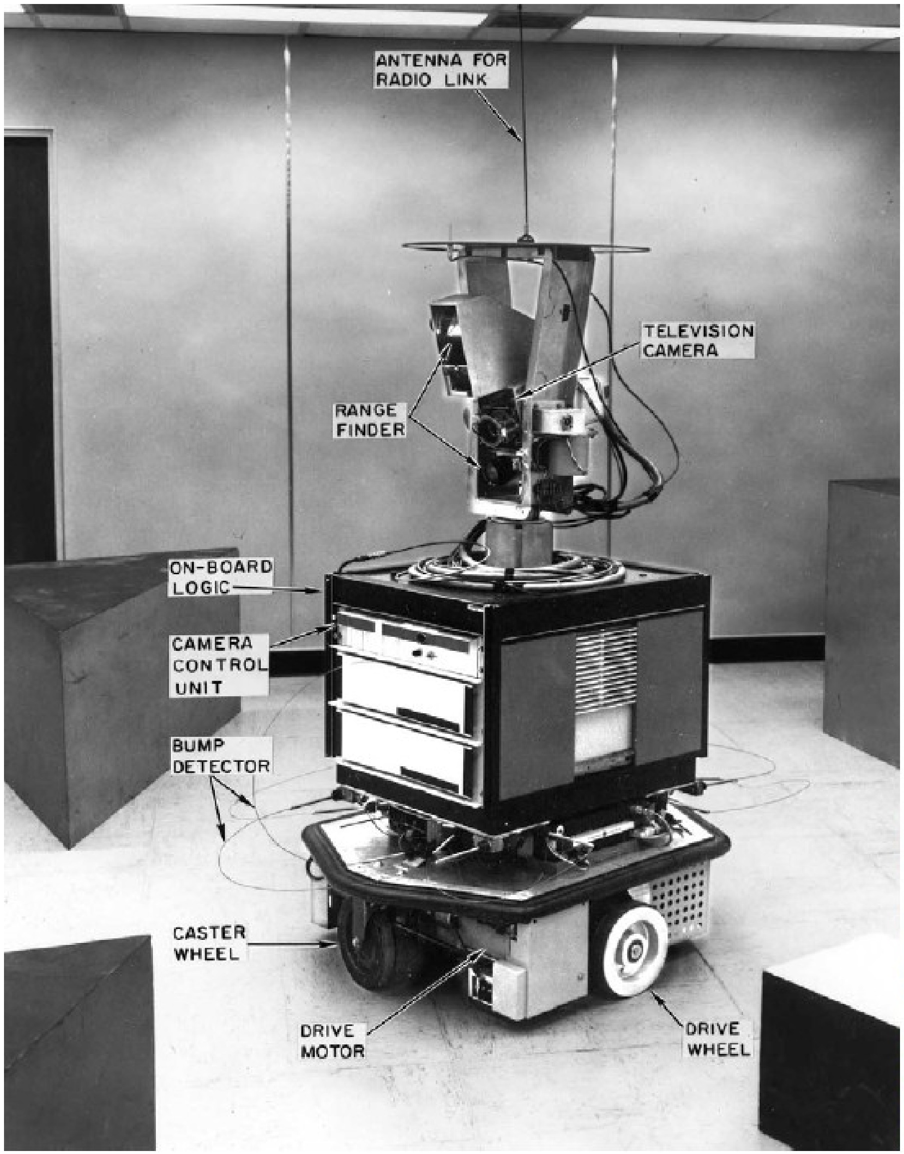


Question: How can the robot measure the result of an action?

Perception for mobile robots



•Case Study 1: Shakey(1966-1972)



- Operating environment:
  - Indoors.
  - Engineered.
- Sensors:
  - Wheel encoders.
  - Bumb detector.
  - Range finder.
  - Camera.

Case Study 2: PR2(2007-)

- Operating environment:
  - Indoors.
  - Engineered.
- Sensors:
  - Wheel encoders.
  - Bumper.
  - IR sensors.
  - Laser range finder.
  - 3D nodding laser range finder.
  - Inertial measurement unit.
  - Pan-tilt stereo camera with texture projector (active).
  - Pressure sensor and accelerometer inside hands.

Reading

- **Chapter 4**. Perception.