Perception I | **Sensors**

Autonomous Mobile Robots

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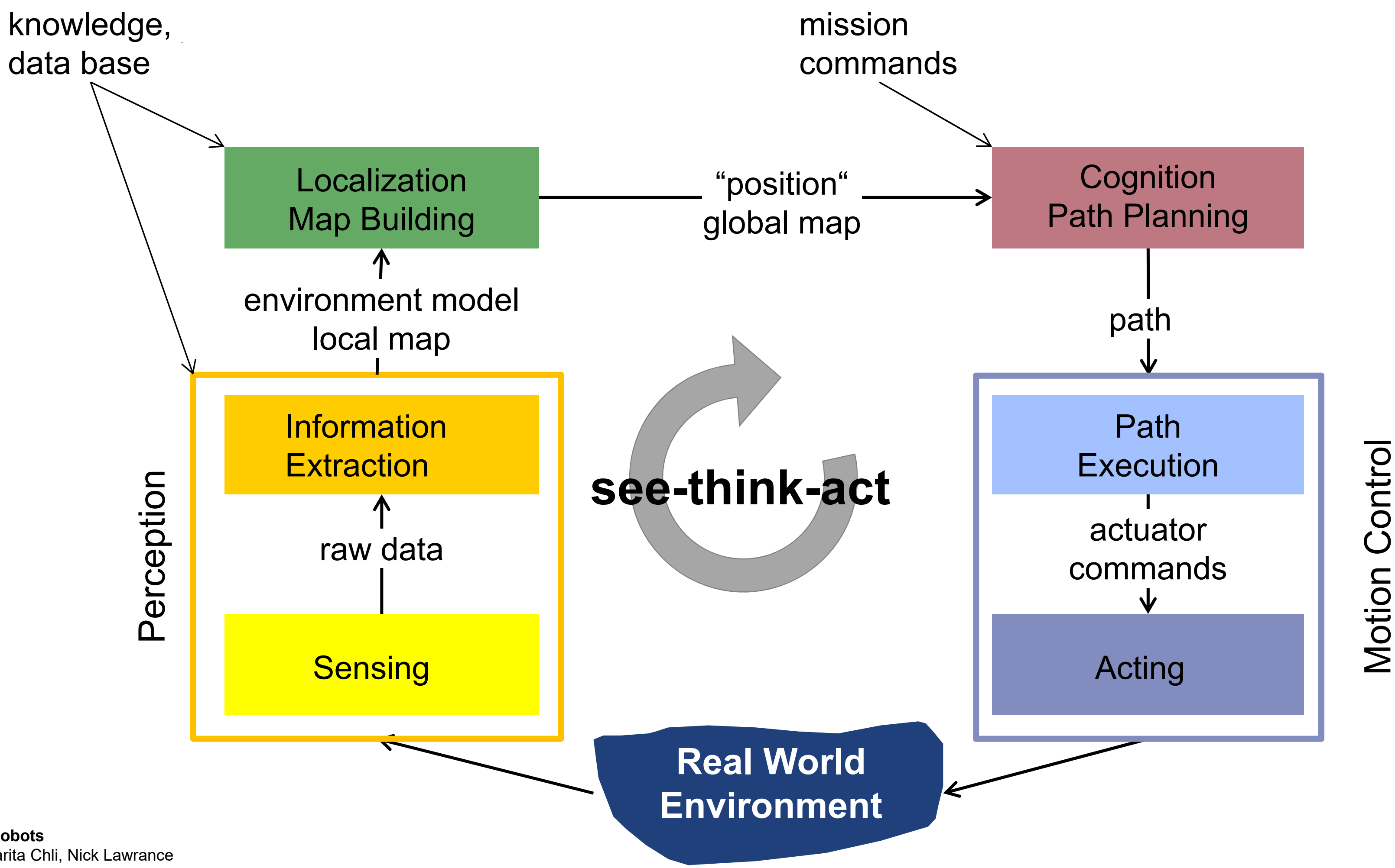
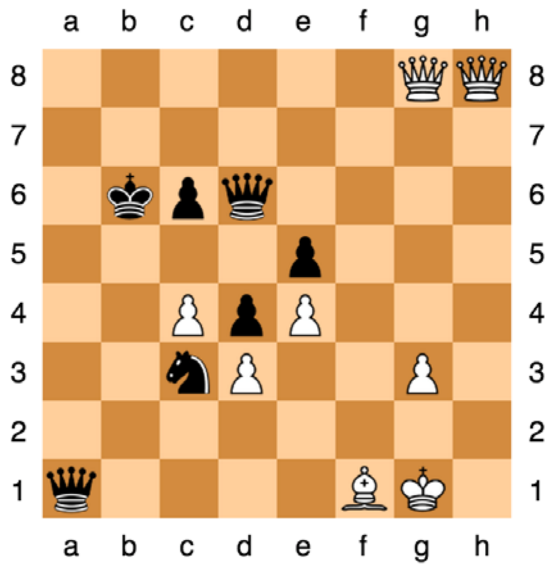
Mobile Robot Control Scheme



Perception is hard!

- "In robotics, the easy problems are hard and the hard problems are easy"
  - S. Pinker. The Language Instinct. New York: Harper Perennial Modern Classics, 1994



beating the world's chess master: EASY

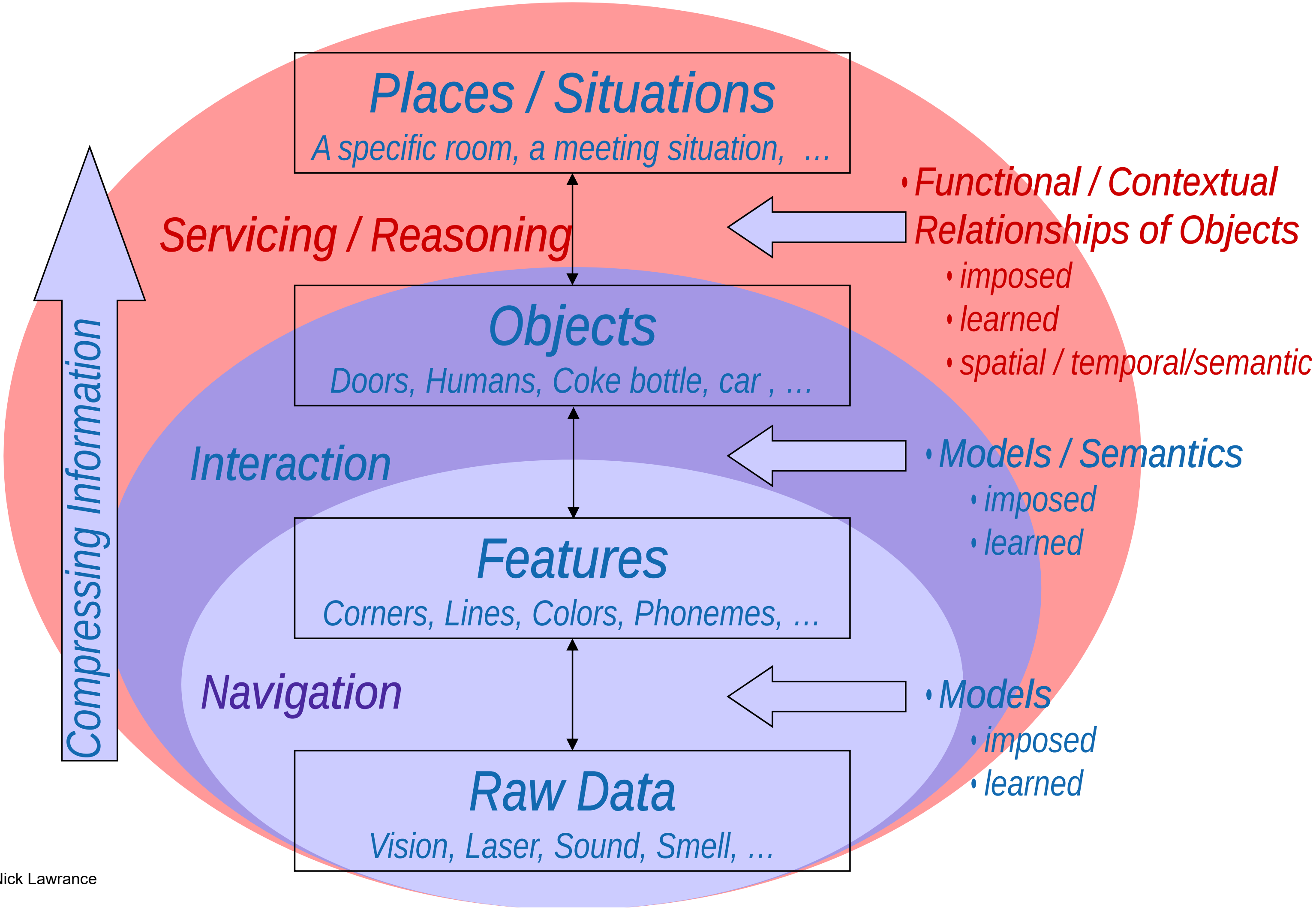
create a machine with some "common sense": very HARD

Robotics | challenges and drivers of technology

- The challenges
  - ***Seeing***, ***feeling*** and ***understanding*** the world
  - Dealing with ***uncertain*** and only ***partially available*** information
  - ***Act*** appropriately onto the environment

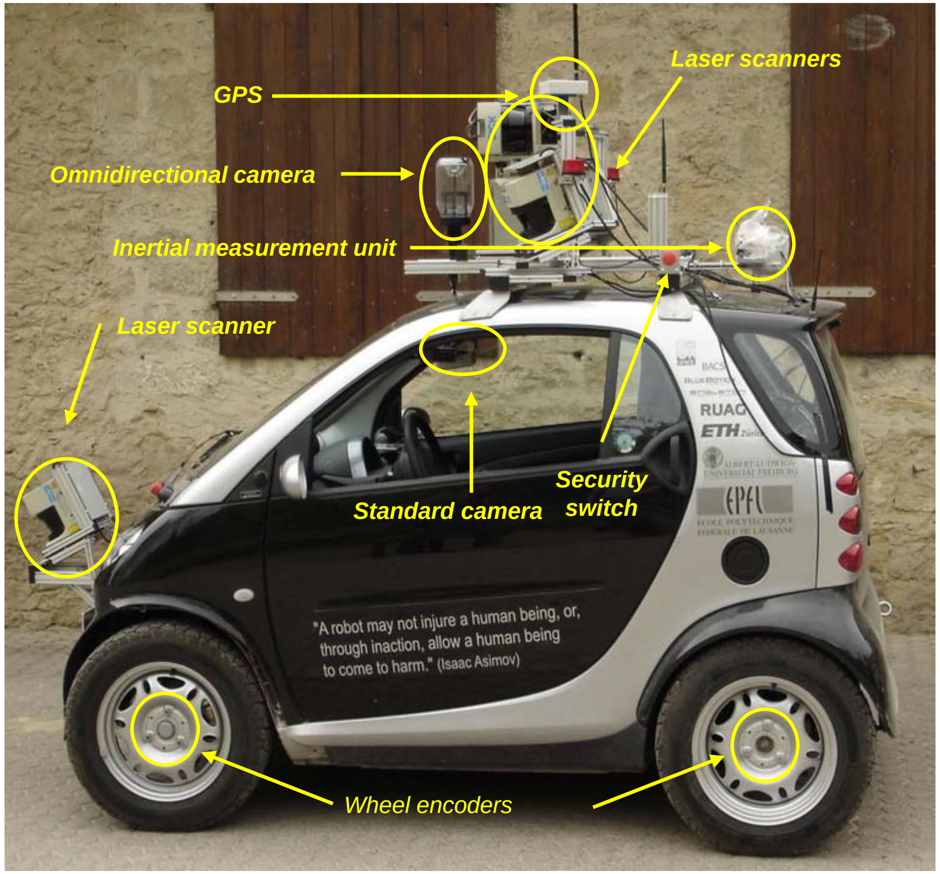
- Technology drivers
  | *technology evolutions enable robotics revolutions*
  - Laser time-of-flight sensors
  - Cameras and IMUs combined with required calculation power
  - Torque controlled motors, “soft” actuation
  - New materials

Perception | definition

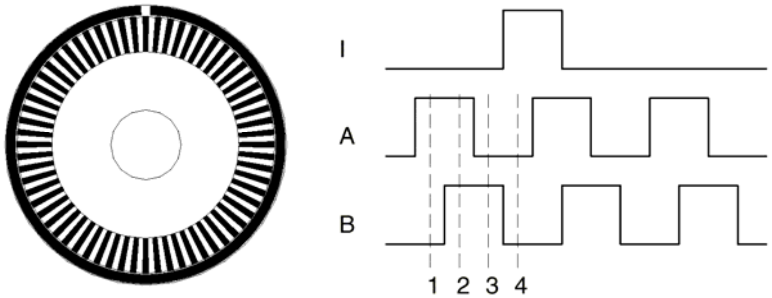


Sensors | common sensors and their use in mobile robotics

- Tactile sensors or bumpers
  - Detection of physical contact, security switches
- GPS
  - Global localization and navigation
- Inertial Measurement Unit (IMU)
  - Orientation and acceleration of the robot
- Wheel encoders
  - Local motion estimation (odometry)
- Laser scanners
  - Obstacle avoidance, motion estimation, scene interpretation (road detection, pedestrians)
- Cameras
  - Texture information, motion estimation, scene interpretation



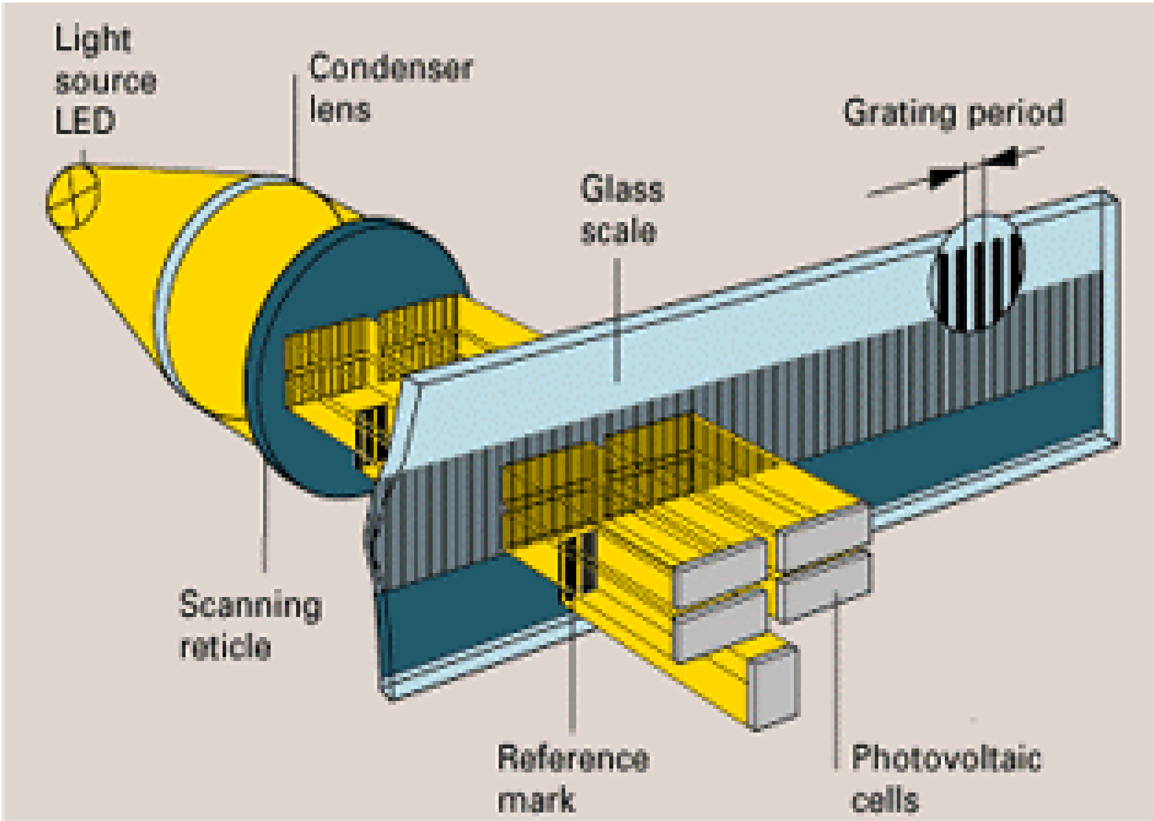
Wheel / Motor Encoders



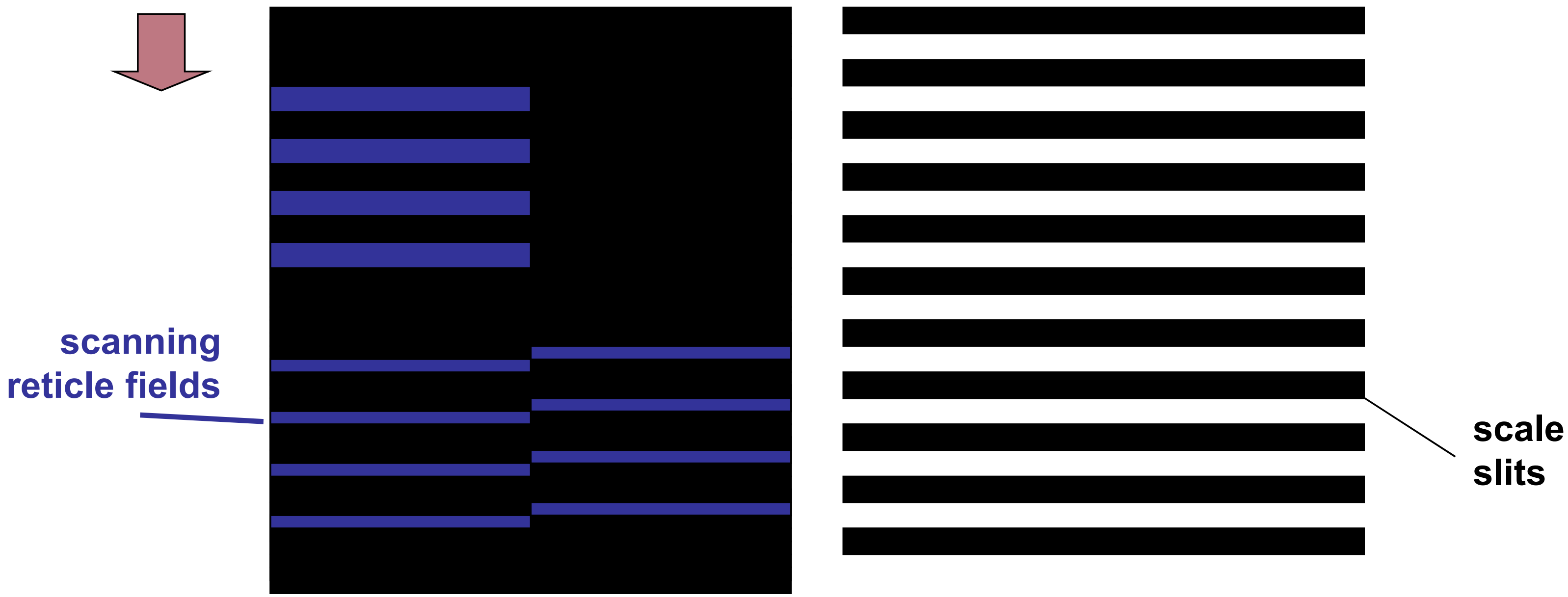
State	Ch A	Ch B
S_1	High	Low
S_2	High	High
S_3	Low	High
S_4	Low	Low

- Use cases
  - measure position or speed of the wheels or steering
  - integrate wheel movements to get an estimate of the position -> odometry
  - optical encoders are proprioceptive sensors
  - typical resolutions: 64 - 2048 increments per revolution.
  - for high resolution: interpolation
- Working principle of optical encoders
  - regular: counts the number of transitions but cannot tell the direction of motion
  - quadrature: uses two sensors in quadrature-phase shift. The ordering of which wave produces a rising edge first tells the direction of motion. Additionally, resolution is 4 times bigger
  - a single slot in the outer track generates a reference pulse per revolution

Wheel / Motor Encoders (2)



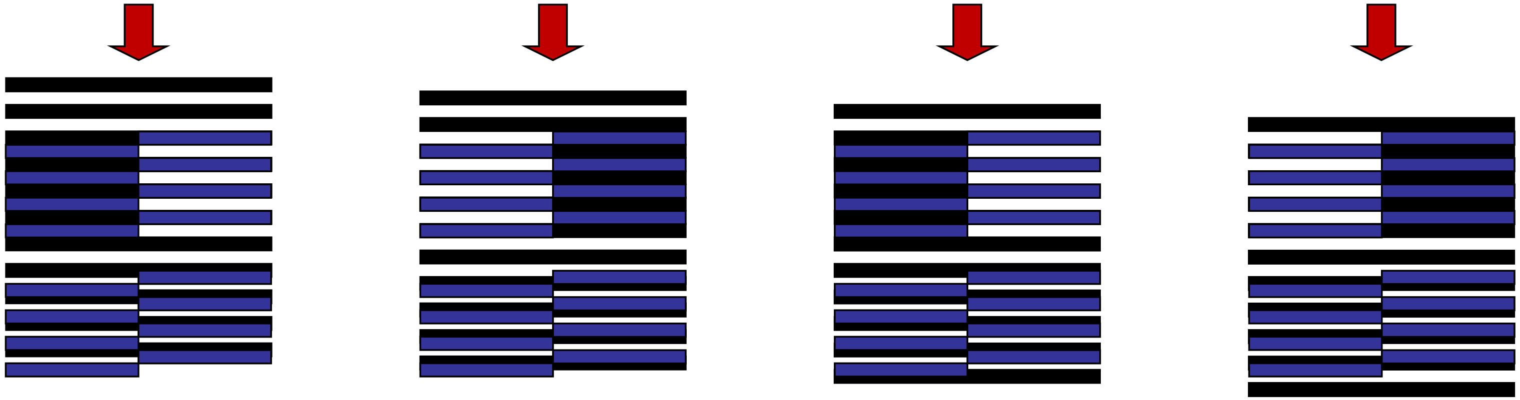
Wheel / Motor Encoders



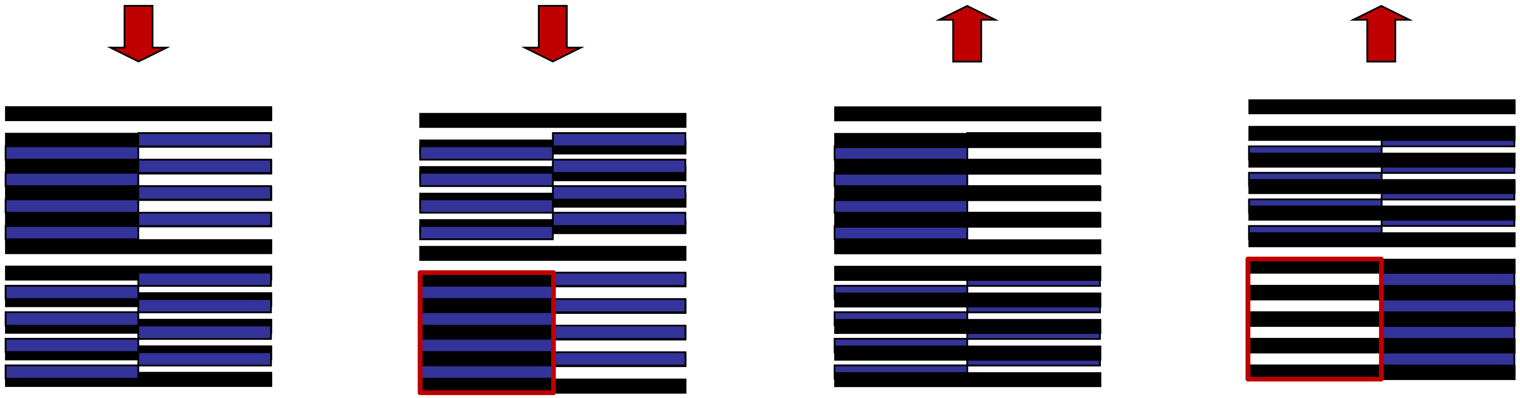
2. Main Characteristics

- The four fields on the scanning reticle are shifted in phase relative to each other by one quarter of the grating period, which equals 360°/(number of lines)
- This configuration allows the detection of a change in direction
- Easy to interface with a micro-controller

Wheel / Motor Encoders



Notice what happens when the direction changes:



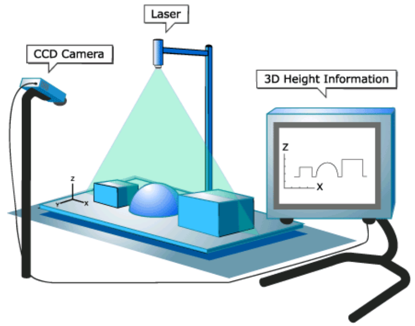
Range sensors

- Sonar

- Laser range finder

- Time of Flight Camera

- Structured light (triangulation)



Range Sensors (time of flight)

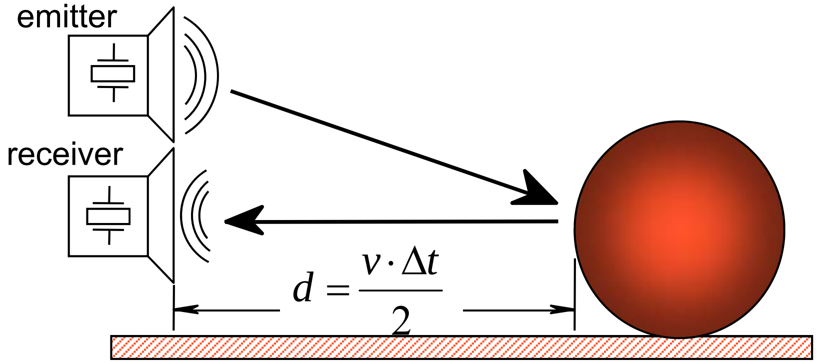
- Large range distance measurement → thus called range sensors
- Range information:
  - key element for localization and environment modeling
- Ultrasonic sensors as well as laser range sensors make use of propagation speed of sound or electromagnetic waves respectively.
- The traveled distance of a sound or electromagnetic wave is given by
  - d = distance traveled (usually round-trip)
  - c = speed of wave propagation
  - t = time of flight.

$$d = c \cdot t$$

Range Sensors (time of flight)

- It is important to point out
  - Propagation speed of sound: 0.3 m/ms
  - Propagation speed of of electromagnetic signals: 0.3 m/ns,
  - Electromagnetic signals travel one million times faster.
  - 3 meters
    - Equivalent to 10 ms for an ultrasonic system
    - Equivalent to only 10 ns for a laser range sensor
    - Measuring time of flight with electromagnetic signals is not an easy task
    - laser range sensors expensive and delicate
- The quality of time of flight range sensors mainly depends on:
  - Inaccuracies in the time of fight measurement (laser range sensors)
  - Opening angle of transmitted beam (especially ultrasonic range sensors)
  - Interaction with the target (surface, specular reflections)
  - Variation of propagation speed (sound)
  - Speed of mobile robot and target (if not at stand still)

Factsheet: Ultrasonic Range Sensor



<http://www.robot-electronics.co.uk/
shop/Ultrasonic_Rangers1999.htm>

1. Operational Principle

An ultrasonic pulse is generated by a piezo-electric emitter, reflected by an object in its path, and sensed by a piezo-electric receiver. Based on the speed of sound in air and the elapsed time from emission to reception, the distance between the sensor and the object is easily calculated.

2. Main Characteristics

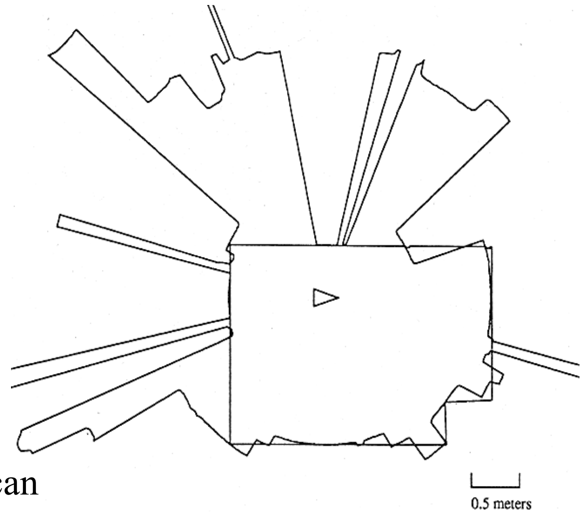
- Precision influenced by angle to object (as illustrated on the next slide)
- Useful in ranges from several cm to several meters
- **Typically relatively inexpensive**

3. Applications

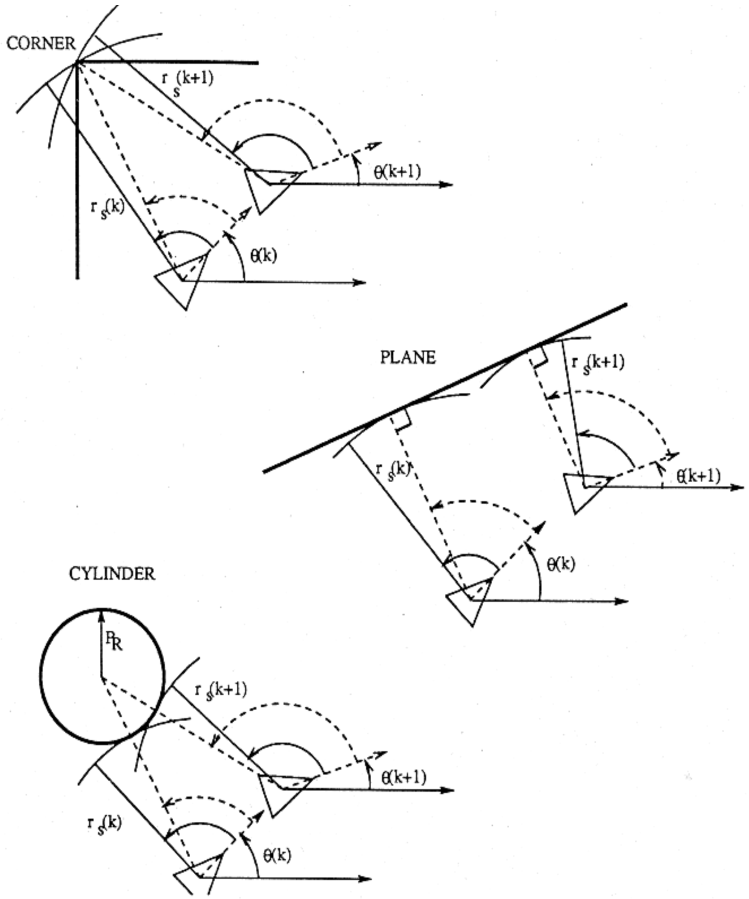
- Distance measurement (also for transparent surfaces)
- Collision detection

Ultrasonic Sensor (time of flight, sound)

- Problems of ultrasonic sensors
  - soft surfaces that absorb most of the sound energy
  - surfaces that are fare from being perpendicular to the direction of the sound → specular reflections



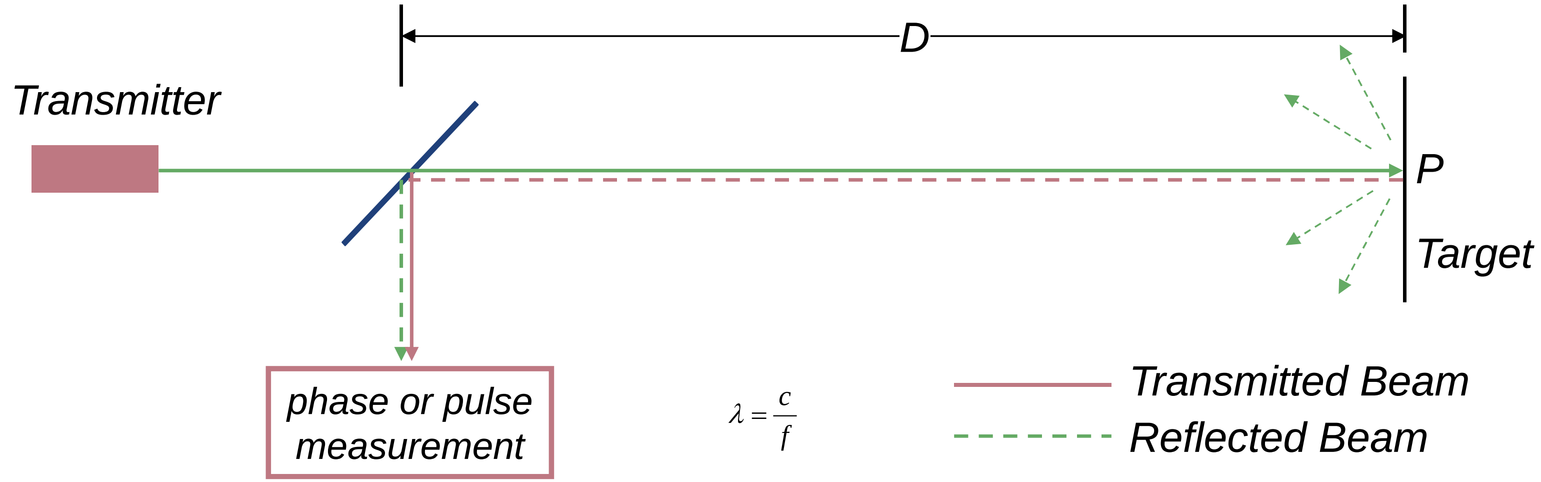
a) 360° scan



b) results from different geometric primitives

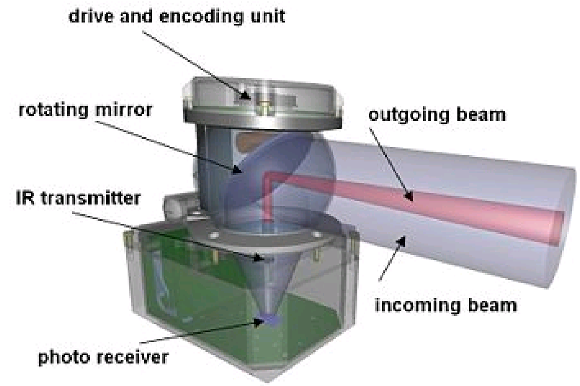
Laser Range Sensor (time of flight, electromagnetic)

- *Phase-Shift Measurement*



$$\lambda = \frac{c}{f}$$

$$D' = 2D = \frac{\theta}{2\pi}\lambda$$

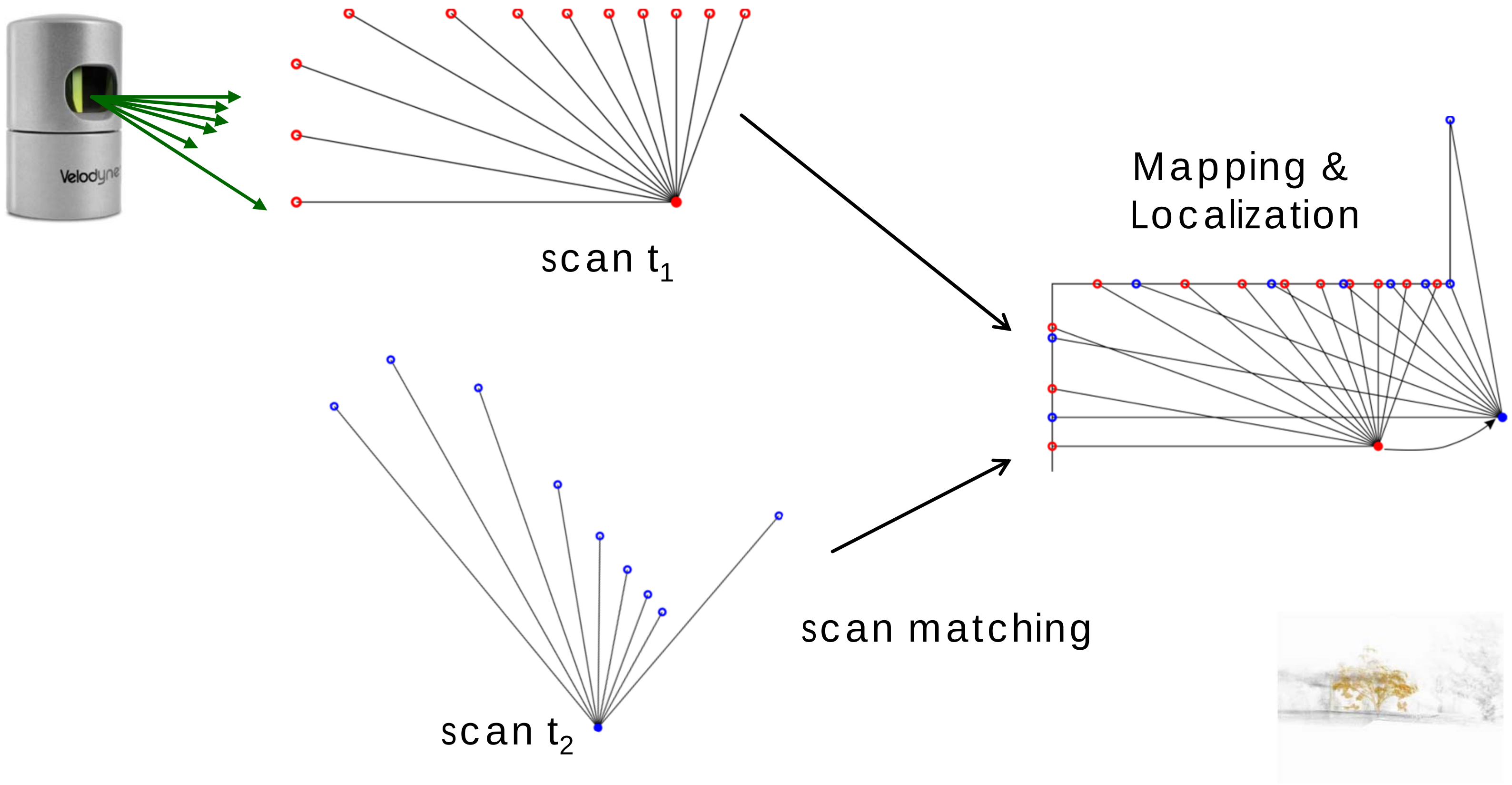


Where:

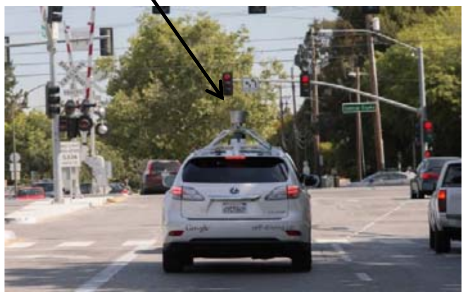
c: is the speed of light; *f* the modulating frequency; *D’* the distance covered by the emitted light.

- for f = 5 MHz (as in the A.T&T. sensor), λ = 60 meters

“Seeing” | Laser-based 3D mapping

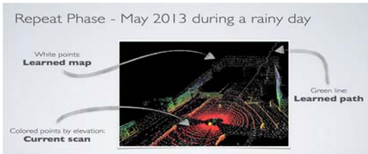


Today | 3D laser sensors → map based navigation



Expensive, complex and cumbersome

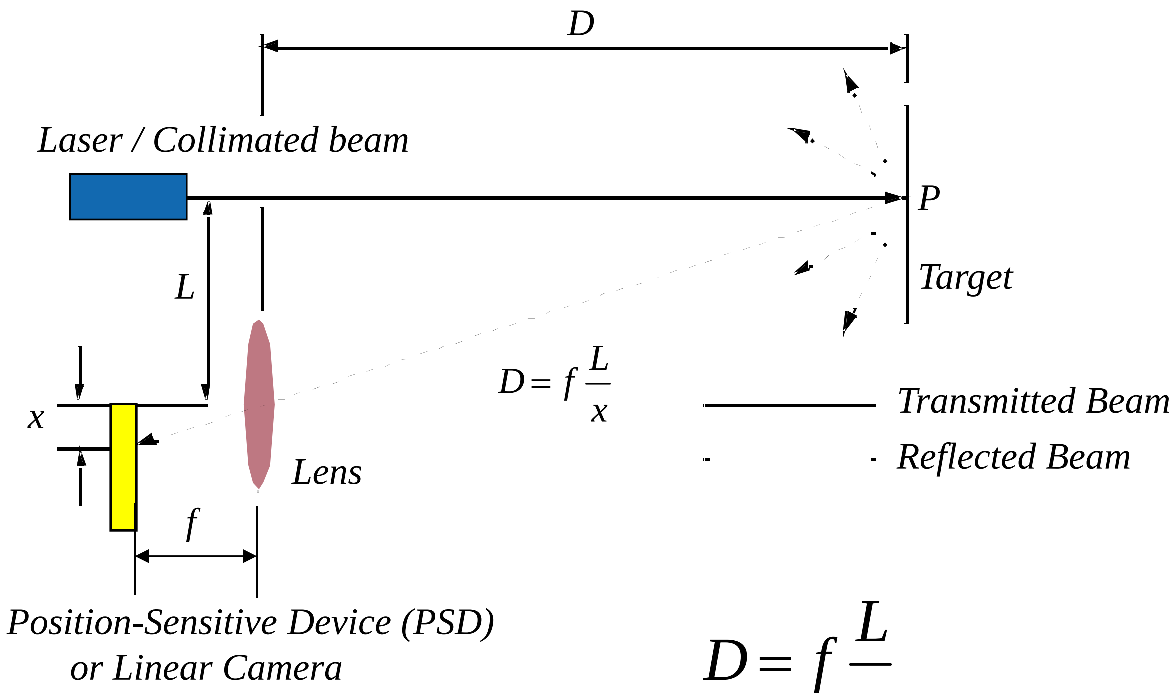
- Google Self-Driving Car Project (status summer 2015)
  - > 20 vehicles in use
  - > 2,7 mio km, 1.5 mio km in autonomous mode
  - > 11 accidents
    - No people insured
    - Non of them caused by car control algorithm



https://www.youtube.com/watch?v=eJCR2TaeSFc

Laser Triangulation (1D)

- Principle of 1D laser triangulation:

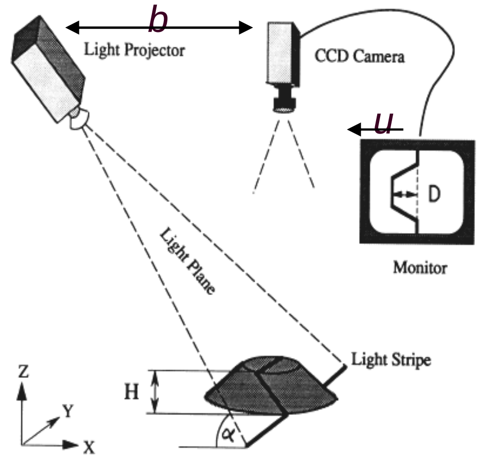


$$D = f\frac{L}{x}$$

Structured light

- Eliminates the correspondence problem by projecting structured light on the scene
- Slits of light or emit collimated light (possibly laser) by means of a rotating mirror
- Light perceived by camera
- Range to an illuminated point can then be determined from simple geometry

a



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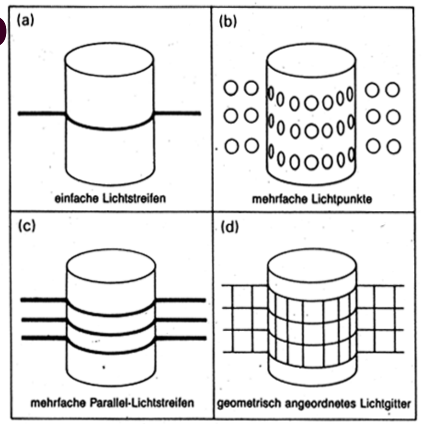

Structured light | Kinect sensor

- Major components
  - IR Projector
  - IR Camera
  - VGA Camera
  - Microphone Array
  - Motorized Tilt