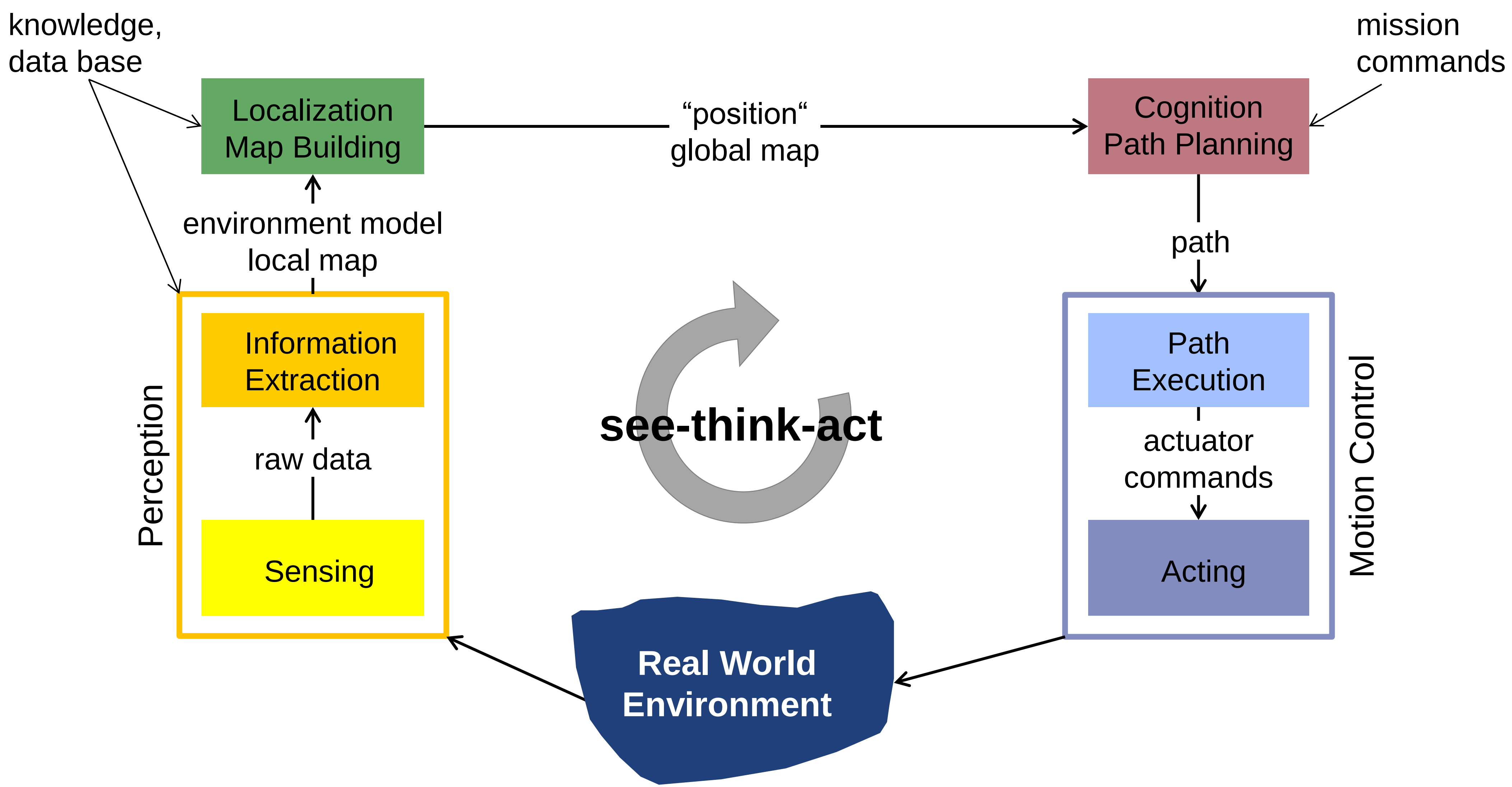
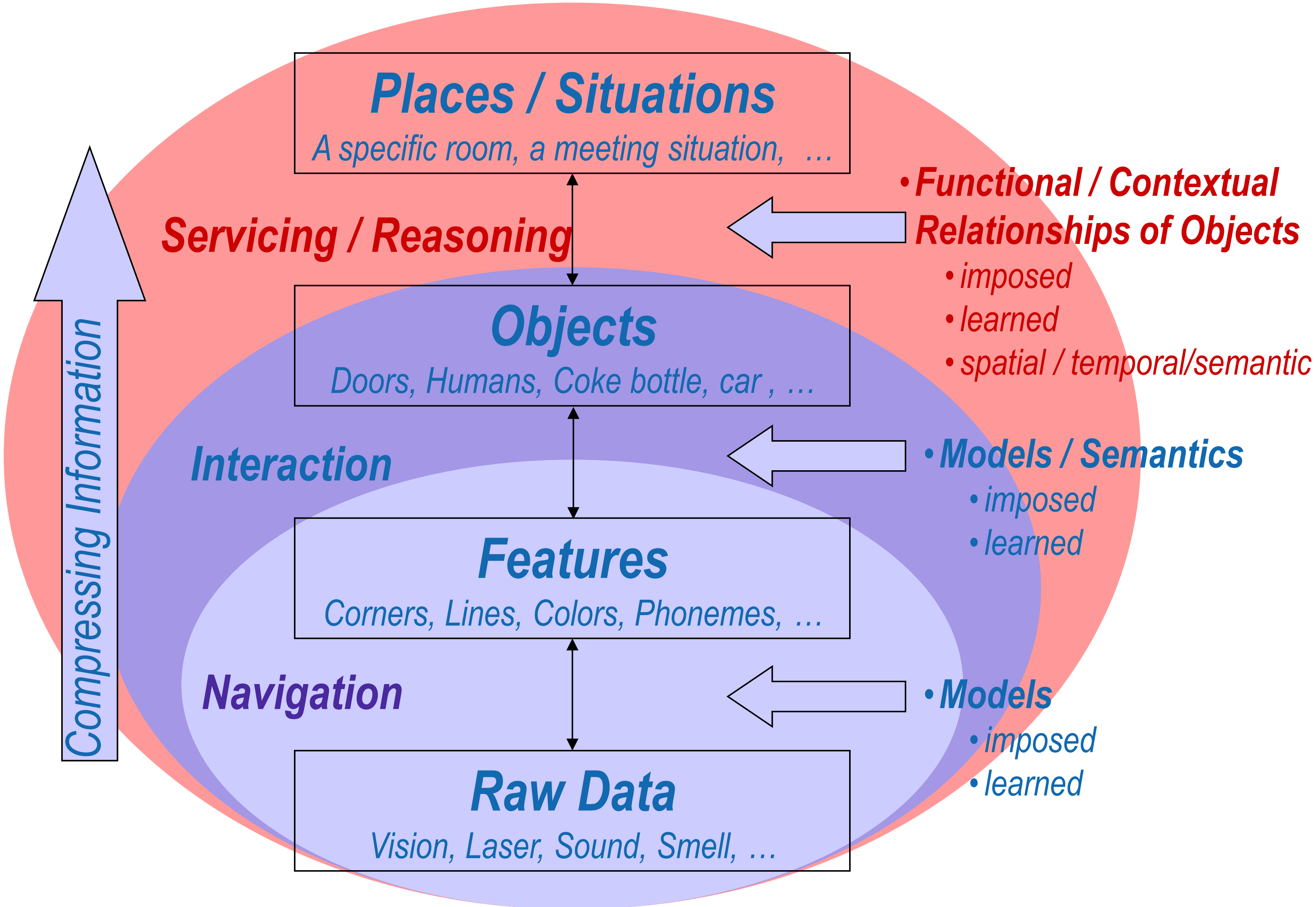
Introduction | perception



Perception | definition



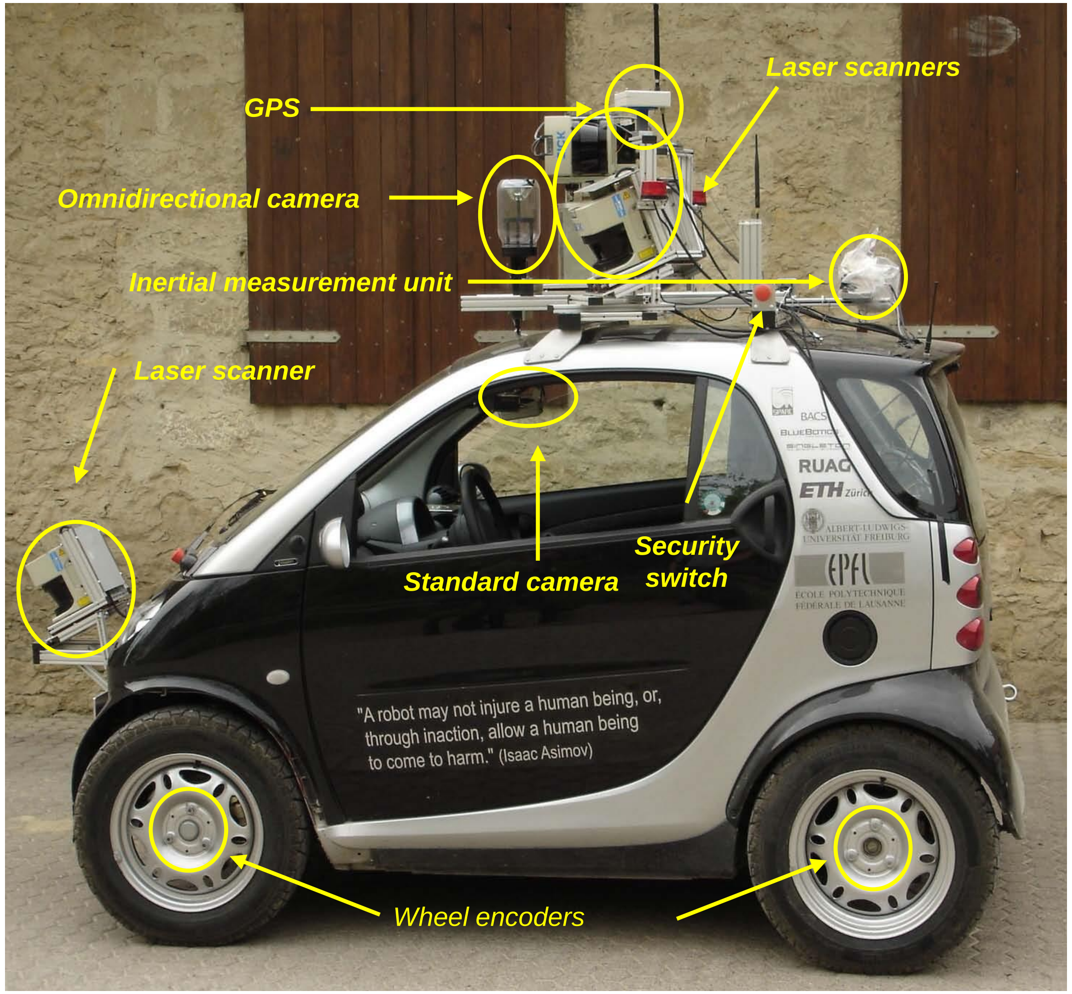
Perception | challenges

- Dealing with real-world situations
- Reasoning about a situation
- Cognitive systems have to interpret situations based on uncertain and only partially available information
- They need ways to learn functional and contextual information (semantics / understanding)

➡ **Probabilistic Reasoning**

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



Classification of sensors

- What:
  - **Proprioceptive sensors**
    - measure values internally to the system (robot),
      - e.g. motor speed, wheel load, heading of the robot, battery status
  - **Exteroceptive sensors**
    - information from the robots environment
    - distances to objects, intensity of the ambient light, extraction of features from the environment
- How:
  - **Passive sensors**
    - Measure energy coming from the environment; very much influenced by the environment
  - **Active sensors**
    - emit their proper energy and measure the reaction
    - better performance, but some influence on environment

Classification of sensors

Sensor type	Sensor System	Proprioceptive (PC) or Exteroceptive (EC)	Active or Passive
Tacticle sensors	Bumbers	EC	P
Wheel/motor sensors	Brush encoders	PC	P
	Optical encoders	PC	A
Heading sensors	Compass	EC	P
	Gyroscope	PC	P
	Inclinometer	EC	A/P
Acceleration sensors	Accelerometer	PC	P
Beacons	GPS	EC	A
	Radio, ultrasonic, reflective beacons	EC	A
Motion/speed sensors	Doppler: radar or sound	EC	A
Range sensors	Ultrasound, laser rangefinder, structured light, time of flight	EC	A
Vision sensors	CCD/CMOS cameras	EC	P

Uncertainty Representation

- Sensing is always related to uncertainties
  - How can uncertainty be represented or quantified?
  - How do they propagate - uncertainty of a function of uncertain values?

- Systematic errors (deterministic)
  - They are caused by factors or processes that can in theory be modeled and, thus, calibrated, (for example, the diameters of the robot wheels, the distance between the wheels, etc.)
- Random errors
  - They cannot be predicted using a sophisticated model but can only be described in probabilistic terms

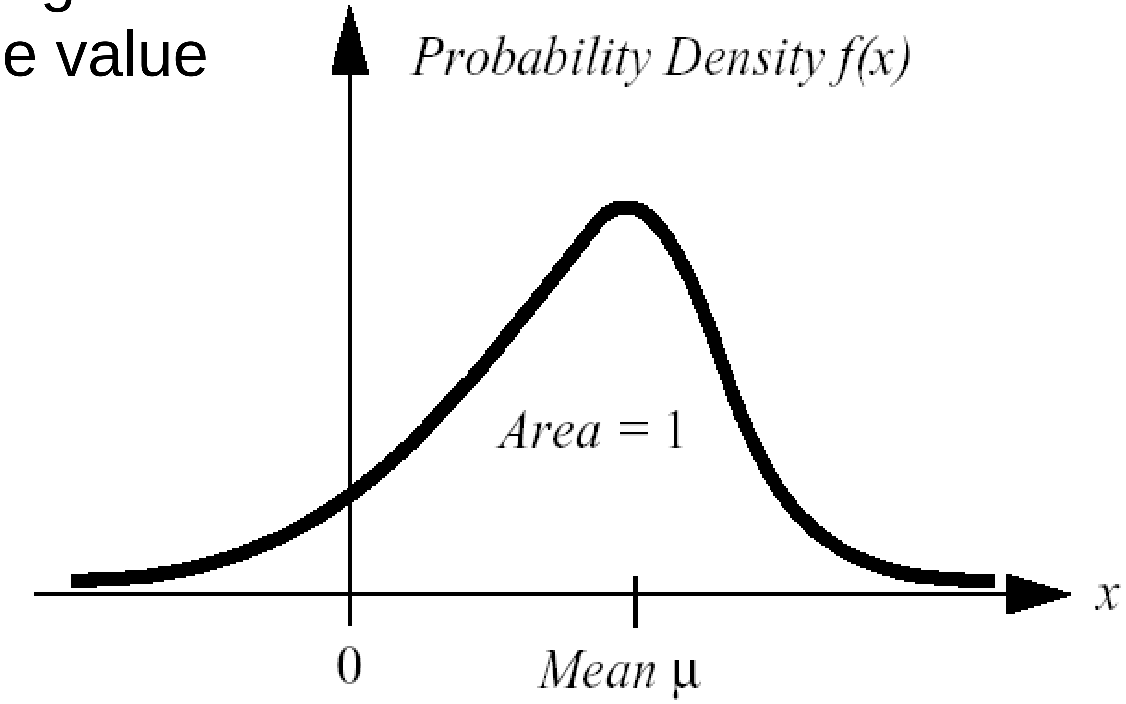
Uncertainty Representation

- The density function identifies for each possible x value of X a probability $f(x)$ density along the y-axis
- The area under the curve is 1, indicating the complete chance of X having some value

$$\int_{-\infty}^{\infty} f(x)dx = 1$$

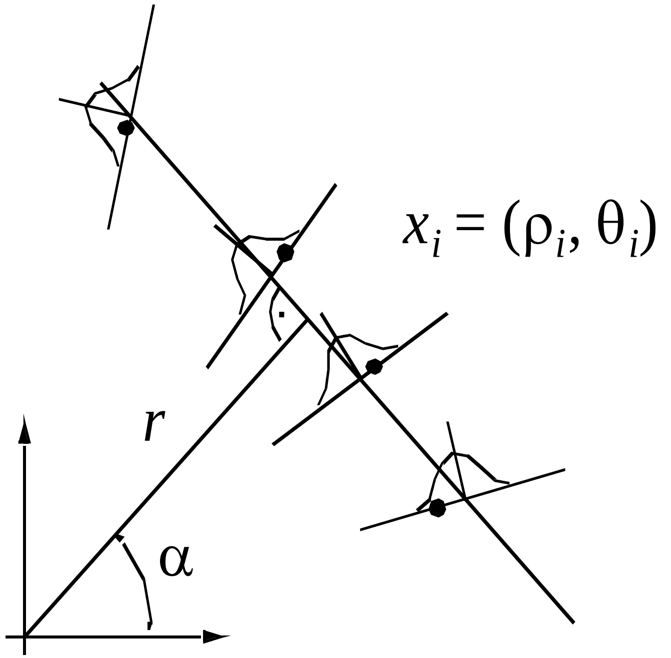
$$\mu = E[X] = \int_{-\infty}^{\infty} xf(x)dx$$

$$\sigma^2 = \int_{-\infty}^{\infty} (x-\mu)^2 f(x)dx$$



Uncertainty Representation | error propagation law

- Imagine extracting a line based on point measurements with uncertainties
- The model parameters ρ_i (length of the perpendicular) and θ_i (its angle to the abscissa) describe a line uniquely
- What is the uncertainty of the extracted line knowing the uncertainties of the measurement points that contribute to it ?



Uncertainty Representation | error propagation law

- Error propagation in a multiple-input multi-output system with n inputs and m outputs

$$Y_j = f_j(X_1 \dots X_n)$$

- It can be shown that the output covariance matrix C_y is given by the error propagation law:

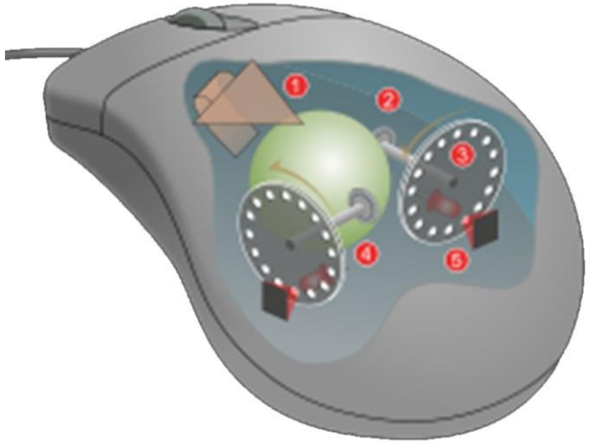
$$C_Y = F_X C_X F_X^T$$

- C_X: covariance matrix representing the input uncertainties
- C_y: covariance matrix representing the propagated uncertainties for the outputs.
- F_X: is the Jacobian matrix defined as:

$$F_X = \begin{bmatrix} \frac{\partial f_1}{\partial X_1} & \cdots & \frac{\partial f_1}{\partial X_n} \\ \vdots & \cdots & \vdots \\ \frac{\partial f_m}{\partial X_1} & \cdots & \frac{\partial f_m}{\partial X_n} \end{bmatrix}$$

Encoder | definition

- **electro-mechanical device** that converts linear or angular position of a shaft to an analog or digital signal, making it an linear/angular transducer

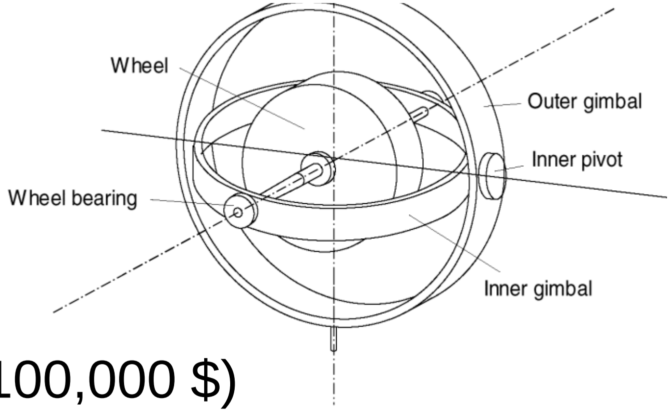


Heading sensors

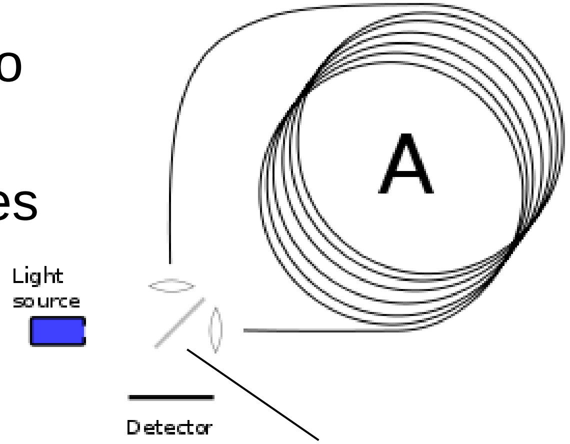
- Definition:
  - Heading sensors are sensors that determine the robot's orientation and inclination with respect to a given reference
- Heading sensors can be proprioceptive (gyroscope, accelerometer) or exteroceptive (compass, inclinometer).
- Together with an appropriate velocity information, they allow integrating the movement to a position estimate.
  - This procedure is called **deduced reckoning** (ship navigation)
- Sensor types:
  - Compass: senses the absolute direction of the Earth magnetic field
  - Gyroscope: senses the relative orientation of the robot with respect to a given reference

Gyroscopes

- Mechanical gyroscopes
  - Angular momentum associated with a spinning wheel keeps the axis of the gyroscope inertially stable.
  - No torque can be transmitted from the outer pivot to the wheel axis however, friction in the axes generates drift
  - Quality: 0.1° drift in 6 hours (a high quality mech. gyro costs up to 100,000 $)

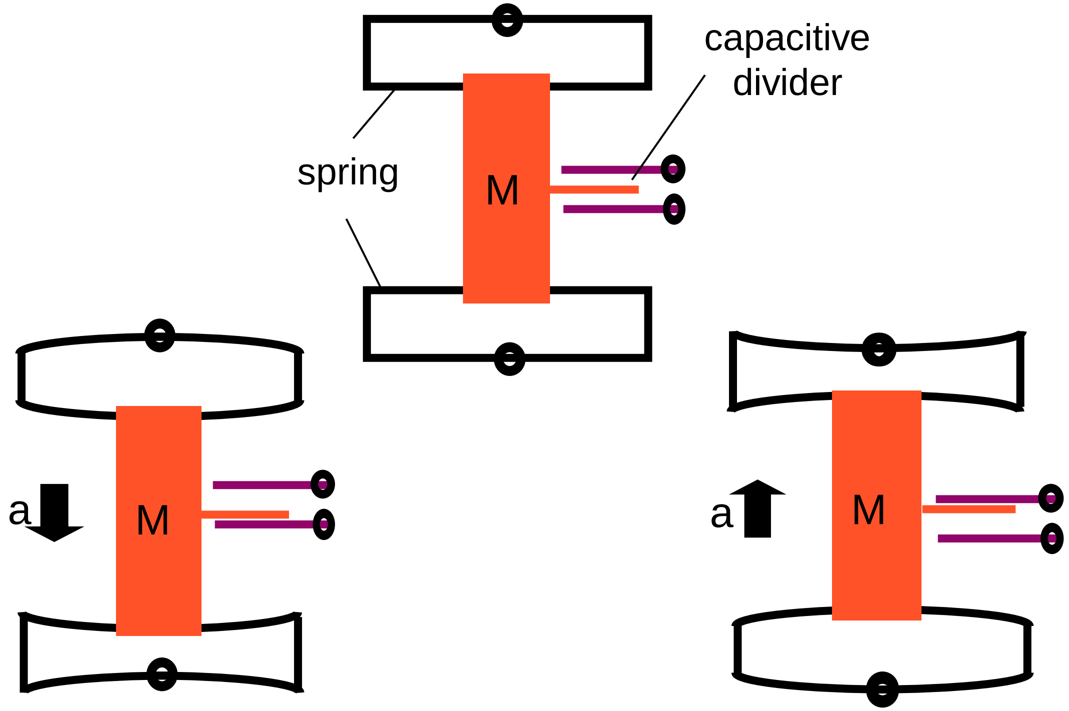


- Optical Gyroscopes
  - Uses two monochromatic laser beams travelling in an optical fiber in two opposite directions
  - The laser beam traveling in direction opposite to the rotation experiences a slightly shorter path (Sagnac effect)
  - The phase shift of the two beams is proportional to the angular velocity



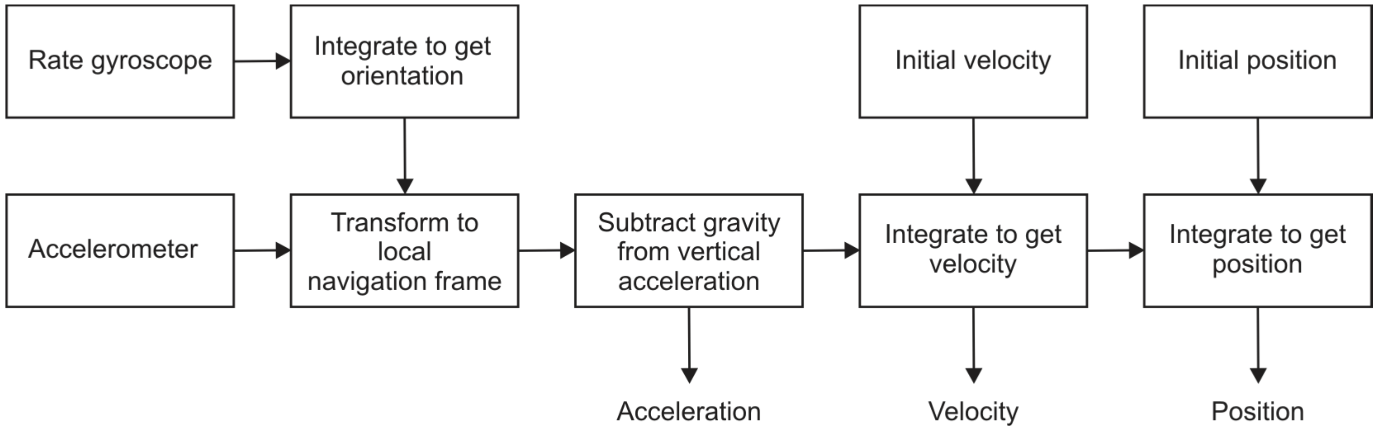
MEMS accelerometer

- A spring-like structure connects the device to a seismic mass vibrating in a capacity divider that converts the displacement into an electric signal
- Can be multi-directional
- Can sense up to 50 g
- Applications
  - Dynamic acceleration
  - Static acceleration (inclinometer)
  - Airbag sensors (+- 35 g)
  - Control of video games (e.g., Nintendo Wii)



Inertial Measurement Unit (IMU)

- It uses gyroscopes and accelerometers to estimate the relative position (x, y, z), orientation (roll, pitch, yaw), velocity, and acceleration of a moving vehicle with respect to an inertial frame
- In order to estimate the motion, the gravity vector must be subtracted and the initial velocity has to be known
- After long periods of operation, drifts occurs: need external reference to cancel it



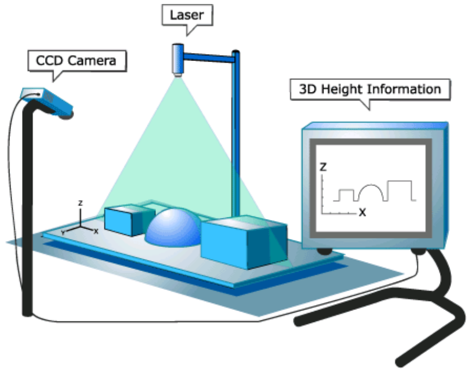
Range sensors

- Sonar
- Laser range finder
- Time of flight camera
- Structured light

sonar

Laser range finder

SwissRanger (time of flight)



Structured light

Kinect 2 (time of flight)

Kinect 1 (structured light)

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

$$d = c \cdot t$$

  - *d* = distance traveled (usually round-trip)
  - *c* = speed of wave propagation
  - *t* = time of flight.

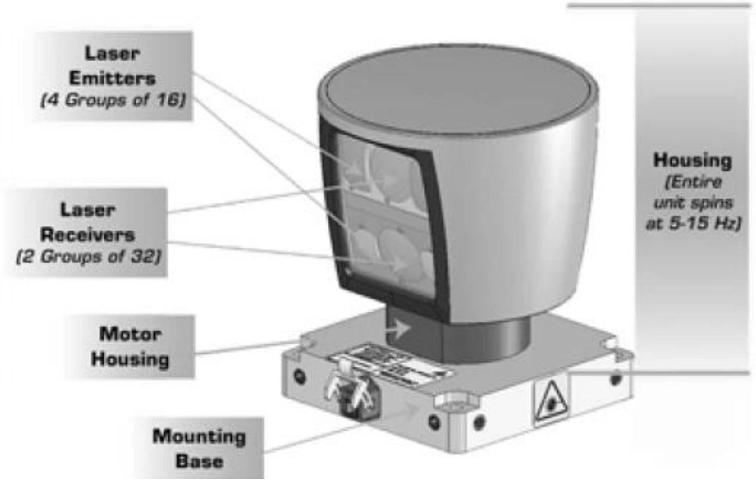
Range sensors (time of flight)

- It is important to point out
  - **Propagation speed v of sound: 0.3 m/ms**
  - **Propagation speed v 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)**

Velodyne laser range finder

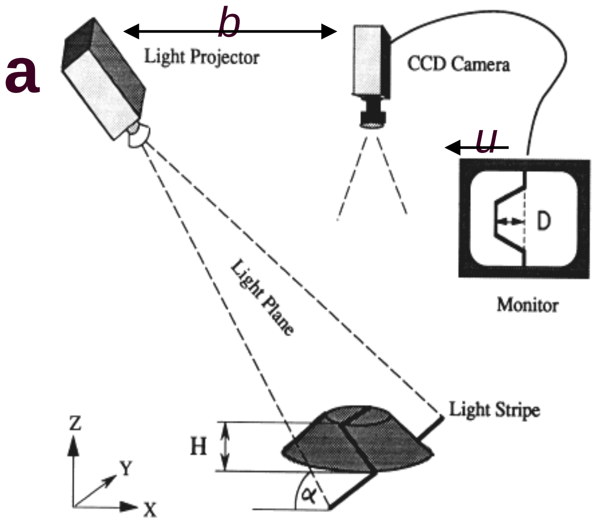
- The Velodyne HDL-64E uses 64 laser emitters.
  - Turn-rate up to 15 Hz
  - The field of view is 360° in azimuth and 26.8° in elevation
  - Angular resolution is 0.09° and 0.4° respectively
  - **Delivers over 1.3 million data points per second**
  - The distance accuracy is better than 2 cm and can measure depth up to 50 m
  - This sensor was the primary means of terrain map construction and obstacle detection for all the top DARPA 2007 Urban Challenge teams. However, the Velodyne is currently still much more expensive than Sick laser range finders (SICK ~ 2-4000 $, Velodyne ~40-80,000 $)

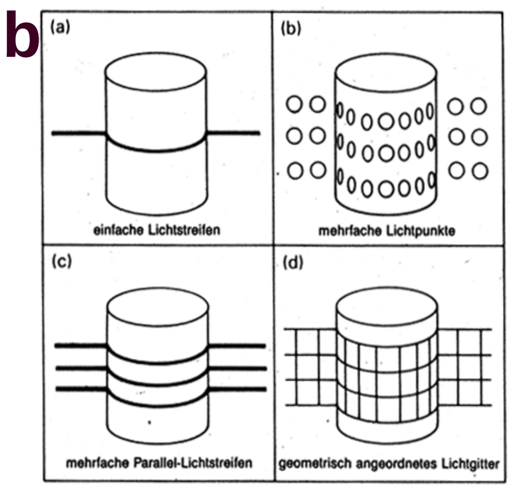


Carnegie Mellon University

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





Structured light | Kinect sensor

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