Introduction to Sensing Technologies for Control

Sensing vs. Perception

transducers - devices that convert some physical phenomenon into electrical signals

A/D conversion - the conversion from analog signal (0-5V) into a fixed precision (typically 8-12 bits) digital representation

perception - the interpretation of signals derived from transducers in order to estimate state information required for control.

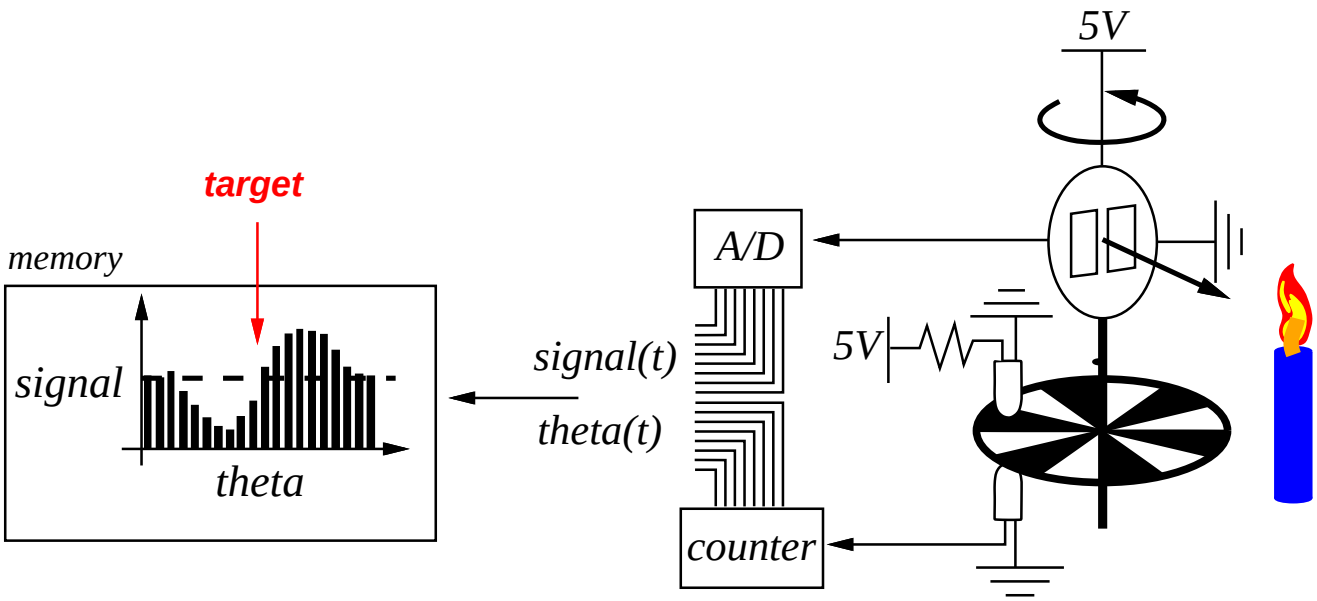
observability - if state $\vec{x}(t_0)$ can be determined given measurements $\vec{z}(t)$ in the interval between t_0 and t_1, then $\vec{x}(t_0)$ is observable. If $\vec{x}(t)$ is observable for all t, $\vec{x}$ is completely observable.

controllability - a system is controllable at time $t_1 > t_0$ if a suitable control $\vec{u}(t)$ can be found to drive the system from an arbitrary $\vec{x}(t_0)$ to another arbitrary state $\vec{x}(t_1)$.

sensory overload - in biology and in many synthetic embedded systems, often too many types of measurements (transducers) are available and are irrelevant in many contexts. Mechanisms for focusing attention on the relevant aspects of state are critical.

Perception for Embedded Control Application

in the most general sense, perception implies abstractions derived from temporal sequences of observations over multiple sensing modalities



Sensor Drivers and Interface Circuitry

photosensors, micro switches, microphones, pyroelectric, near IR reflectance, sonar, strain gauges, gyroscopes, accelerometers, force, compasses, vision,...

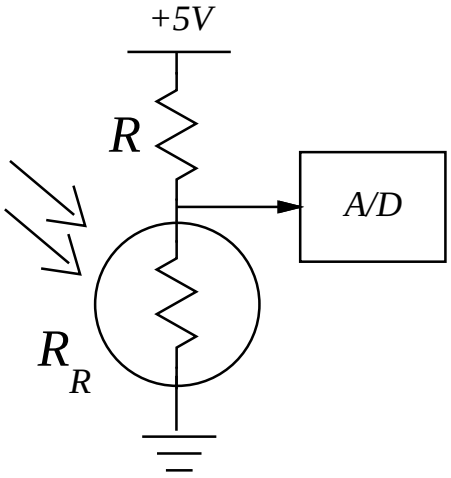
sensitivity, S - a property of the transducer and describes the Δx (physical quantity) that is required to produce a Δr (change in response)...

$$\frac{\Delta r}{r} = S\frac{\Delta x}{x}$$

range, R - the range in the observable quantity x that maps onto the 0-5 V transducer output

resolution - the smallest Δx that can be observed, i.e., $R/255$ (linear transducer and 8-bit A/D).

Light Sensors



Photoresistor

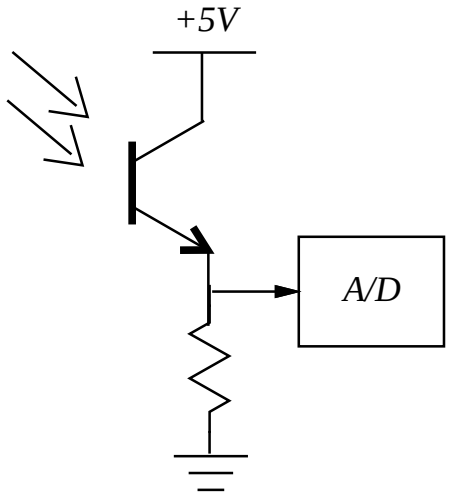
- voltage divider

$$V_{signal} = \frac{R_R}{R + R_R}(5V)$$

- choose $R = R_R$ when ambient light is midrange
- Cadmium Sulfide (CdS)
- cheap

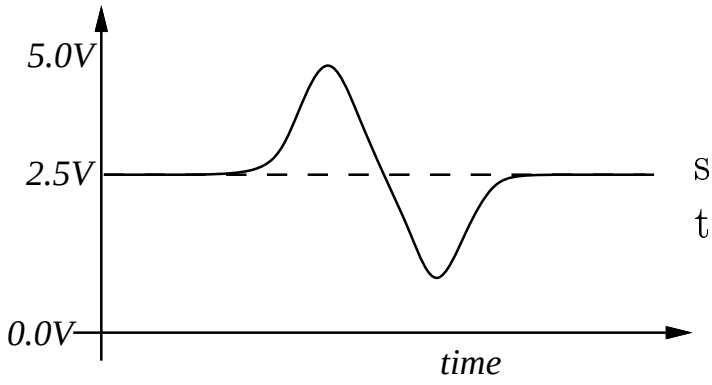
Phototransistor

- greater sensitivity



Pyroelectric Sensors

- lithium tantalate crystal is heated by thermal radiation inducing charge
- tuned to $8 - 10\mu m$ radiation - respond to "human" IR signiture
- motion detecting burglar alarm
- Eltec 442-3 sensor - two elements, Fresnel optics, output proportional to the difference between the charge on the left crystal and the charge on the right crystal.



source moving from the left to the right receptive field

Other Common Sensor Technologies

- force
  - strain gauges - foil, conductive ink
  - piezoelectric films
  - conductive rubber
  - capacitive force
  - rheostatic fluids
- Sound
  - microphones
  - sonar
- position
  - microswitches
  - shaft encoders
  - gyros
  - tilt/compasses
- proprioceptive
  - battery-level
  - motor current - stall, external force
  - temperature

Perception

vestibular - cutaneous tactile - visual - auditory
olfactory - proprioceptive

...a richly encoded representation of the relationship between the agent and the world.

Percept Inversion

"If sensory stimuli are produced in such and such a way by the world, then what must the world have been like to produce this stimulus"?

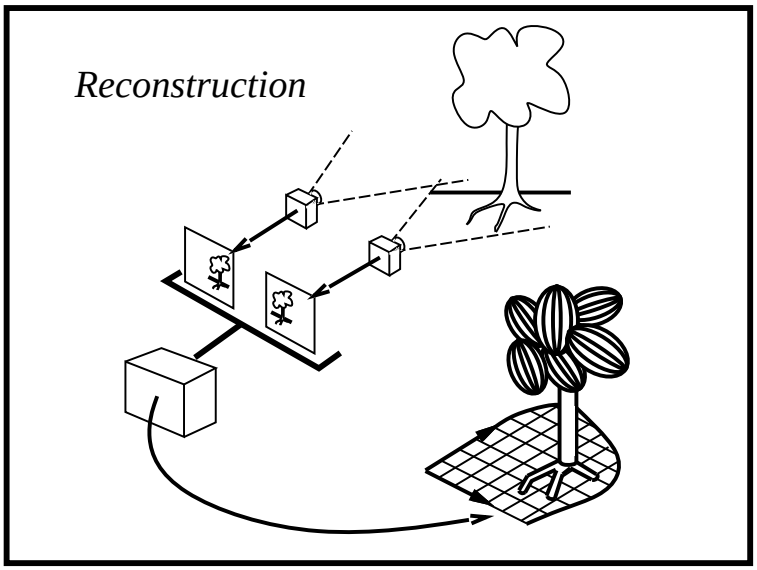
$$Stimulus = f(World) \qquad World = f^{-1}(S)$$

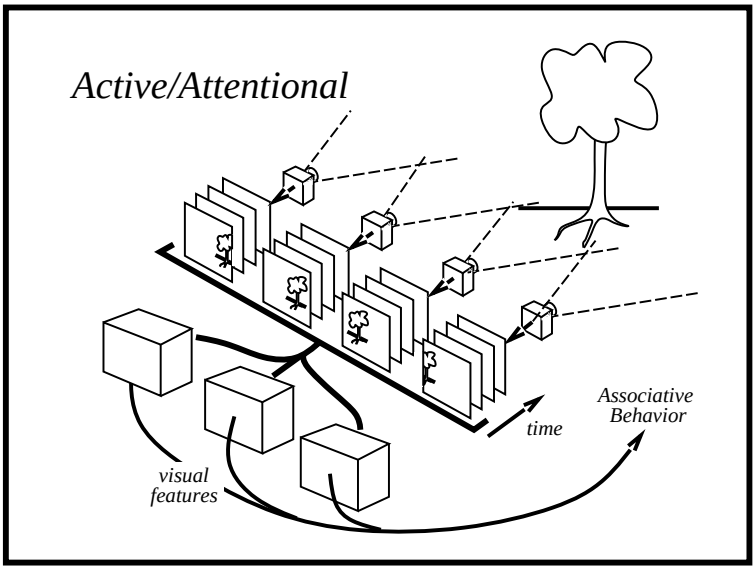
- the functions, $f()$, are only partially known,
- in general, the inverse of $f()$ is not well-conditioned

$$\Downarrow$$

knowledge and **experience** (richly associative sensor information) can fill in initially inaccessible detail

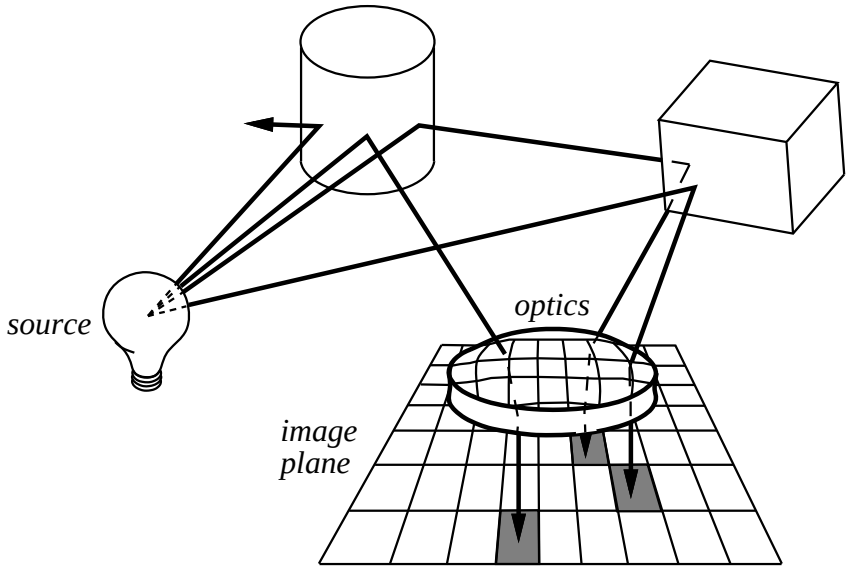
Embodied Perceptual Systems





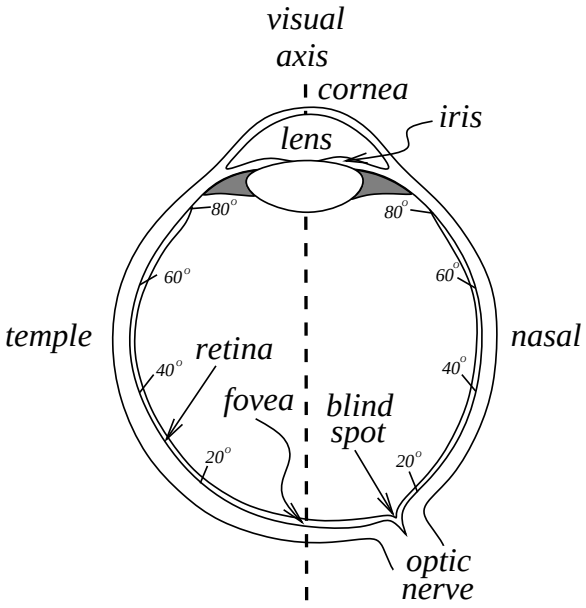
adapted from material presented by Bob Bolles at the 1993 International Symposium on Intelligent Control

Vision - Image Acquisition



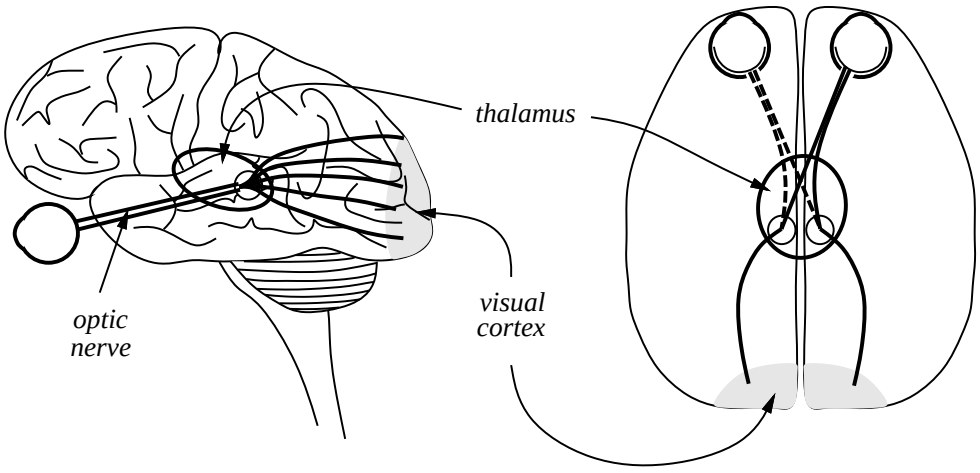
- Energy from a light source is radiated uniformly over 4π steradians.
- **irradiance** and consists of the sum of all incident radiation.
- **radiance** describes the energy leaving a surface and differs from the irradiance by energy transmitted into and absorbed.
- Reflection can be **diffuse** or **specular** depending on surface properties and wavelength.
- Reflected electromagnetic energy sources modulate the **spectral content**, **intensity**, and **polarization** of the incident light.
- the **radiant intensity function** is projected onto a 2D **image plane**, **sampled** spatially, and **digitized** 30 times each second.

Human Eye

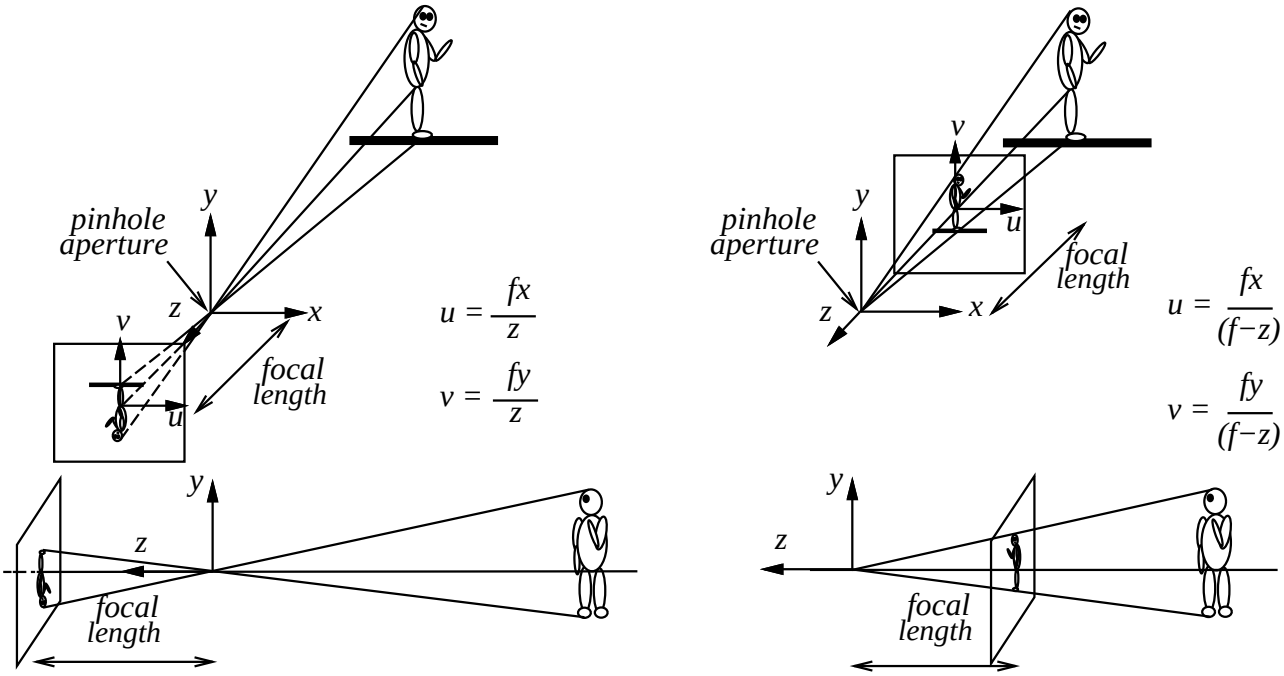


The photosensitive **retina** consists of a total of about 100×10^6 receptors ($512 \times 512 = 0.25 \times 10^6$).
rods measure intensity
cones respond to red-green-blue bands of the visual spectrum.

Roughly 0.8×10^6 nerve fibers exit the eye via the **optic nerve**.

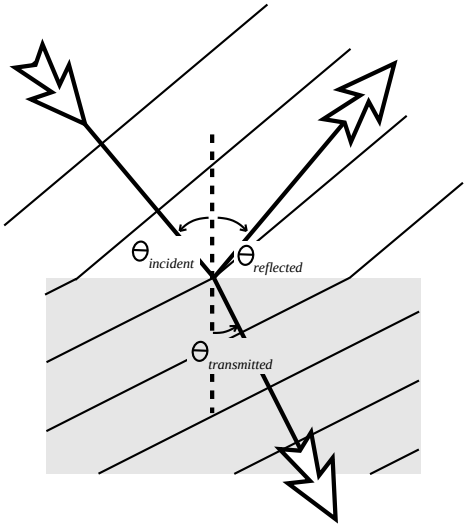


Pinhole Camera - Perspective Distortion



- **vanishing point** - point at which parallel lines in three space meet on the image plane due to perspective distortion.
- **orthographic projection** - as range goes to infinity, the geometric distortion due to variations in depth goes to zero.
- **shallow structure** - images of objects whose depth is small compared to their range are approximately orthographic.

Optics - Snell's Law



Index of Refraction — the ratio of the speed of light in a vacuum to that in the optical material.

$$n = \frac{c}{v} = \sqrt{\frac{\epsilon\mu}{\epsilon_0\mu_0}}$$

where

μ – magnetic permeability, and

ϵ – electric permittivity.

$$\frac{sin(\theta_{incident})}{sin(\theta_{transmitted})} = \frac{n_t}{n_i},$$

Optics - Gaussian Lens Formula

$$\frac{1}{Z} + \frac{1}{Z'} = \frac{1}{f}$$

where:

- Z – distance from the lens to the object
- Z' – distance from the lens to place where the image is formed
- f – focal length of the lens