Institute of
Applied Physics
Friedrich-Schiller-Universität Jena

Metrology and Sensing

Lecture 3-1: Sensors

2020-11-17

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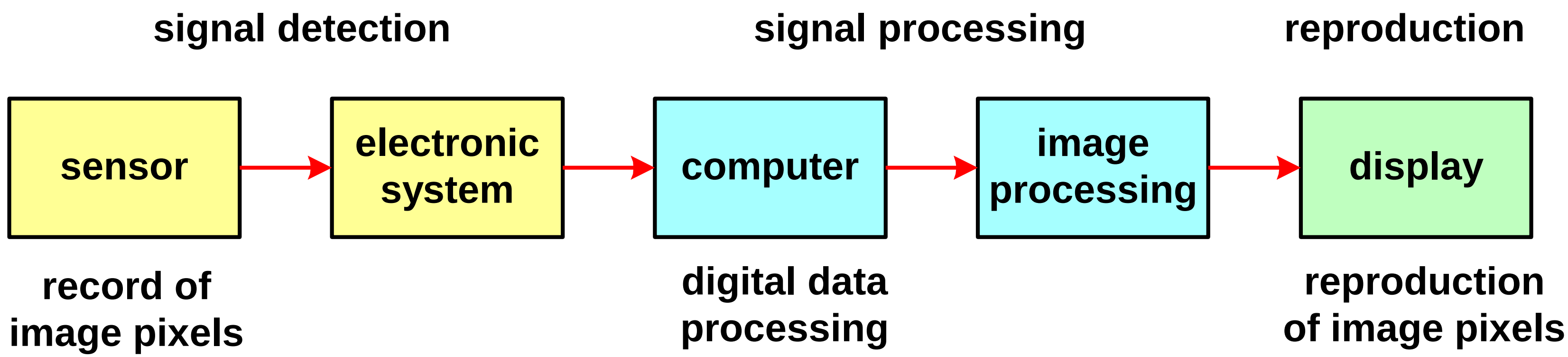
Content

- Introduction
- Basic properties

Signal Chain

- Signal chain



- Optical signal detection

$$S(x,y)=\left[K\cdot B(x,y)*T(x,y)\right]\cdot Comb(x,y)+N_D(x,y)$$

T : transfer function
B : signal conversion
N : noise

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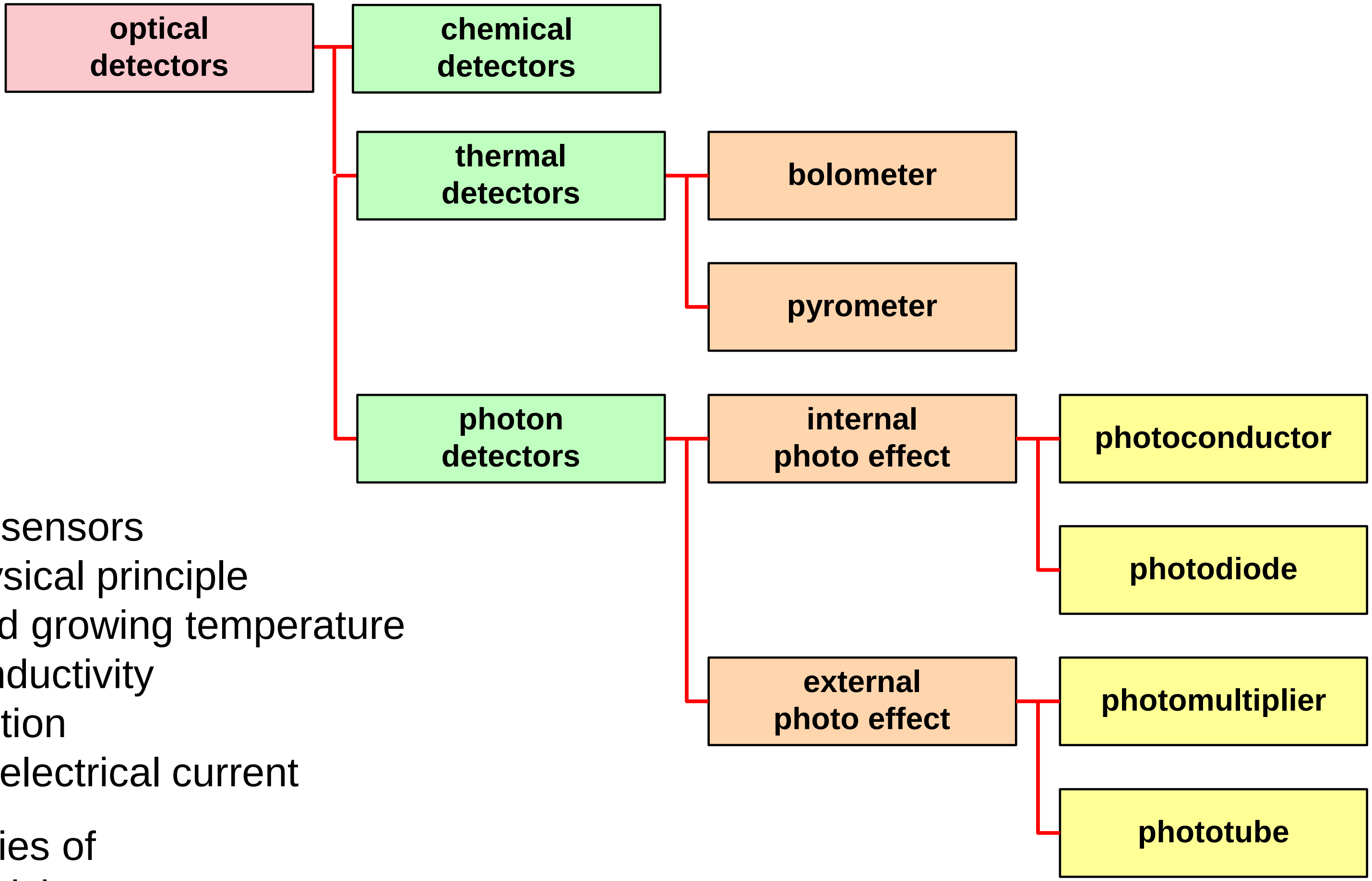
Classification of Optical Sensors

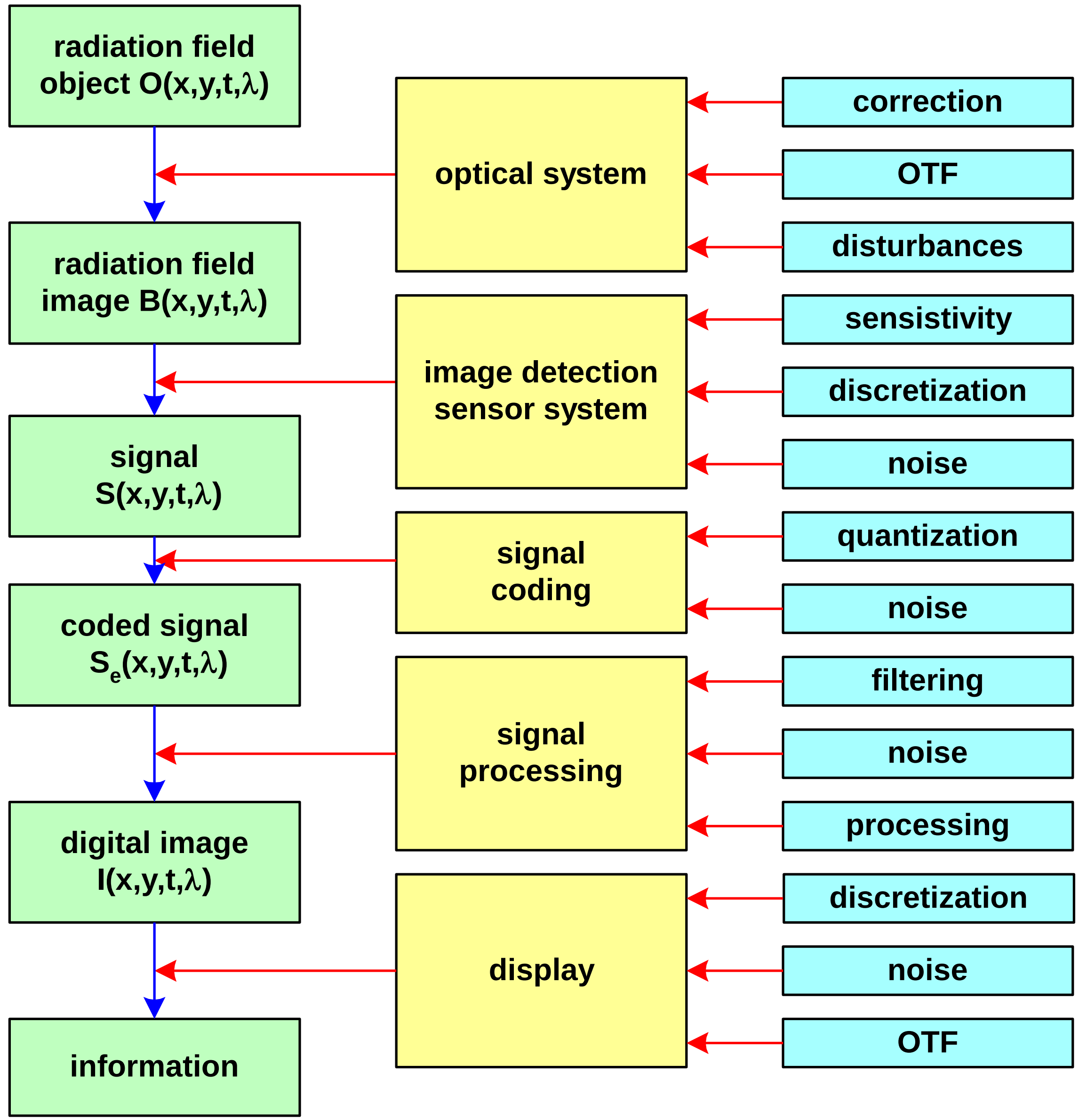


- Classification of sensors according to physical principle
  1. absorption and growing temperature
  2. change of conductivity
  3. chemical reaction
  4. generation of electrical current
- Different properties of
  1. spectral sensitivity
  2. time behavior
  3. dependence on temperature
  4. sensitivity of signal power

Signal Recording

- Recording of a signal

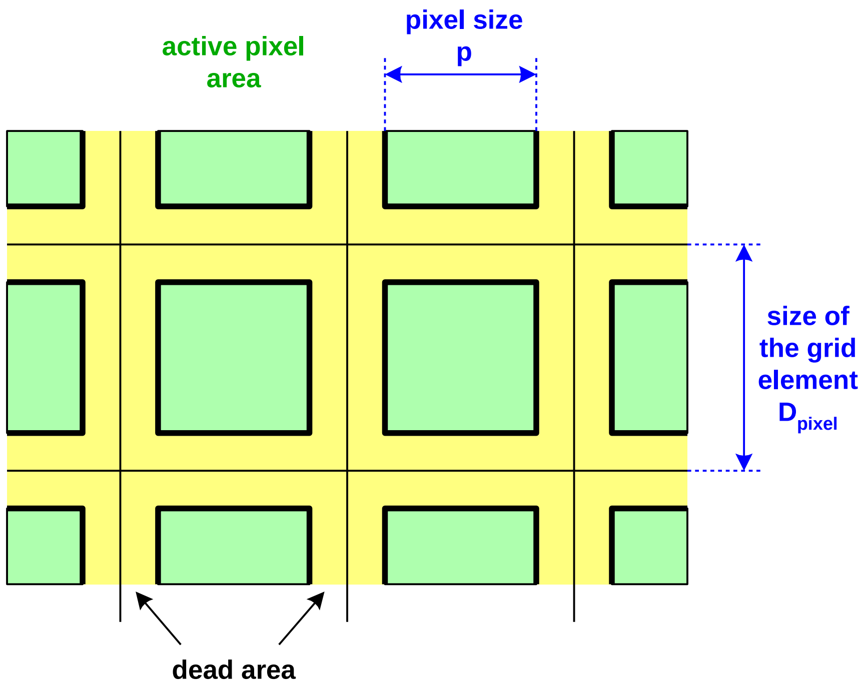
- Dependencies:
  1. space coordinate and angle
  2. time
  3. wavelength

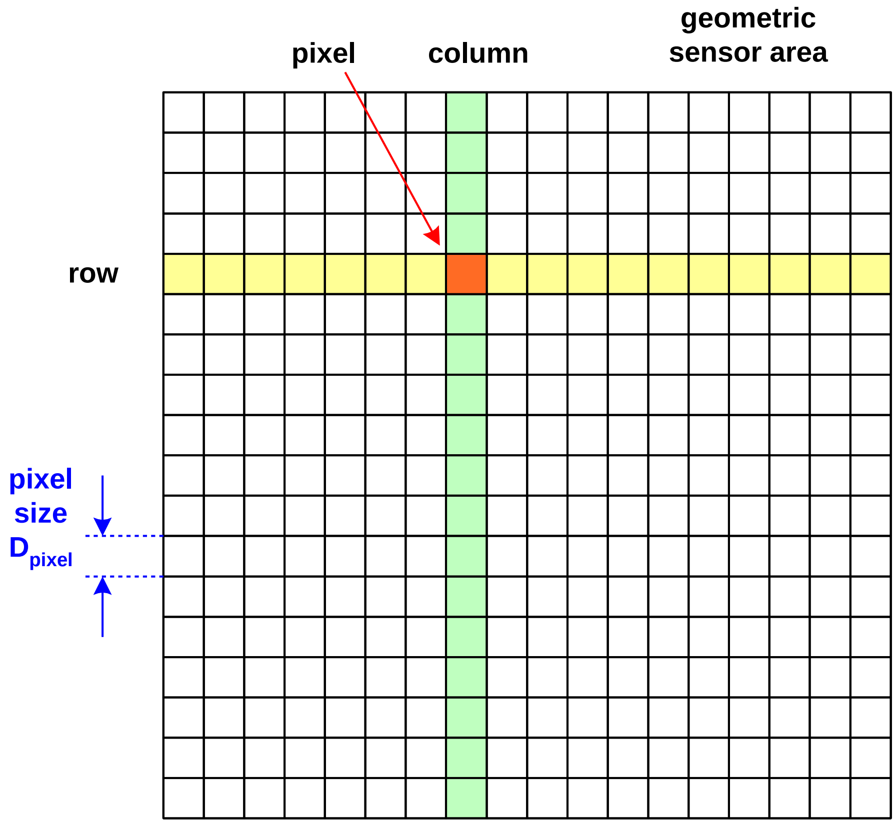


Discretizaion and Pixelation

- 2D sensor:
  Discrete pixel of finite size
- Dead zones between pixels:
  finite effective area of signal collection

$$\eta = \left(\frac{p}{D_{pixel}} \right)^2$$



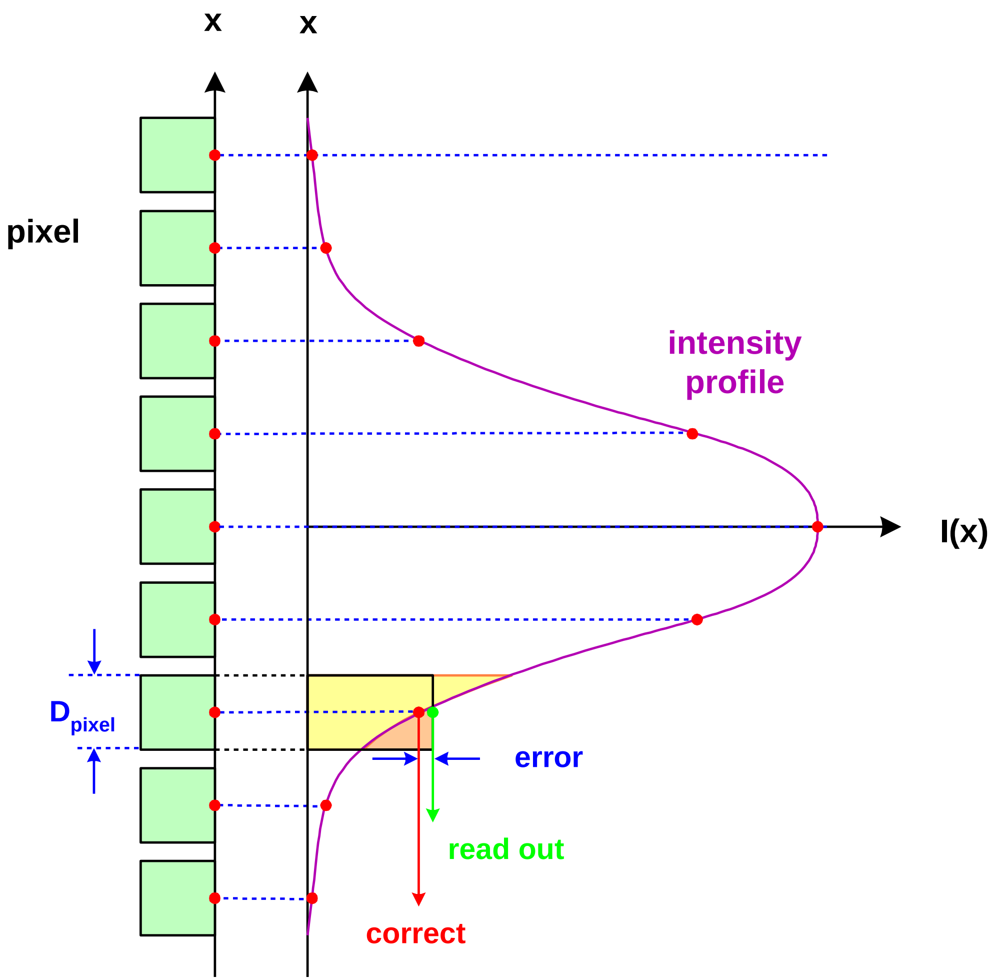


Pixelation and Quantization

- Discrete pixel area of finite size
  1. integration
  2. averaging
  3. dead area
  4. finite spatial resolution

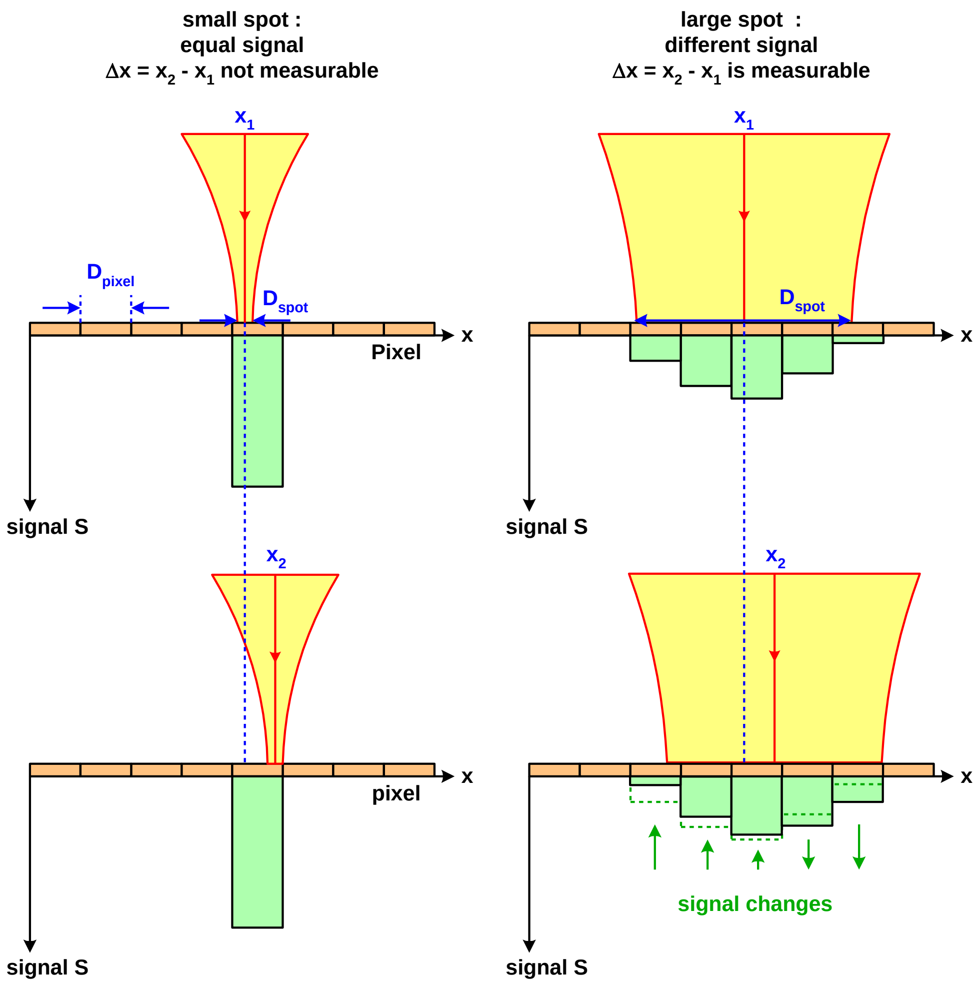
- Nyquist frequency of spatial resolution

$$v_{Ny} = \frac{1}{2D_{pixel}}$$



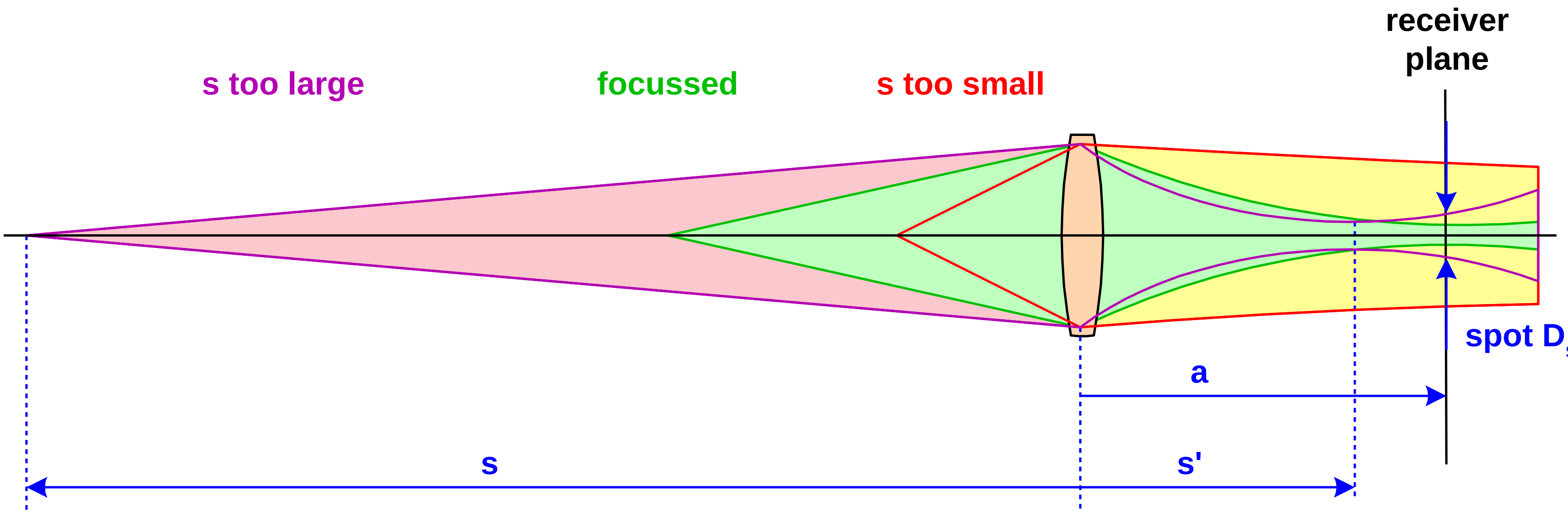
Resolution and Spot size

- The spot position is more accurate, if its size is larger than the pixel width
- The signal is changed in many pixels, this is more accurate
- Spot inside one pixel: exact position cannot be distinguished



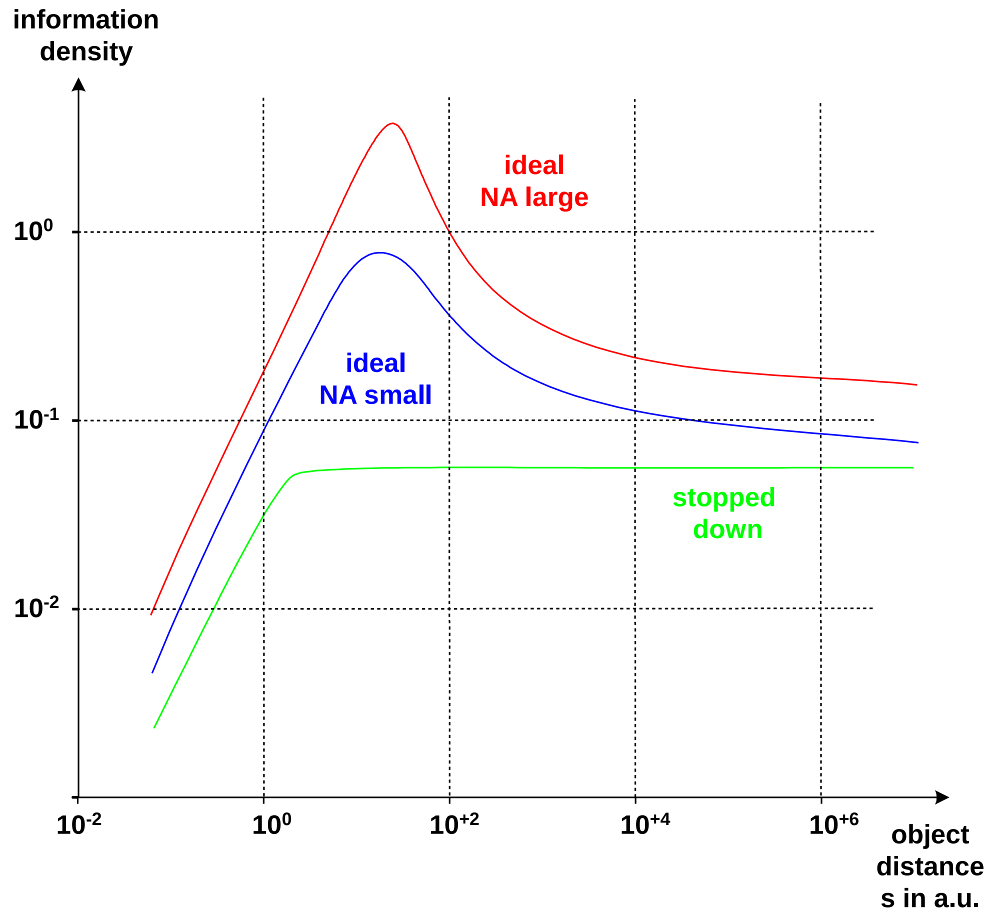
Gain of Information

- Optical system with fixed camera position
- Change of object distance:
  - s too small: broadening of spot
  - focussed: optimal signal transfer
  - s too large: broadening of spot, saturation for extreme distances



Gain of Information

Gain of information as a function of the object distance

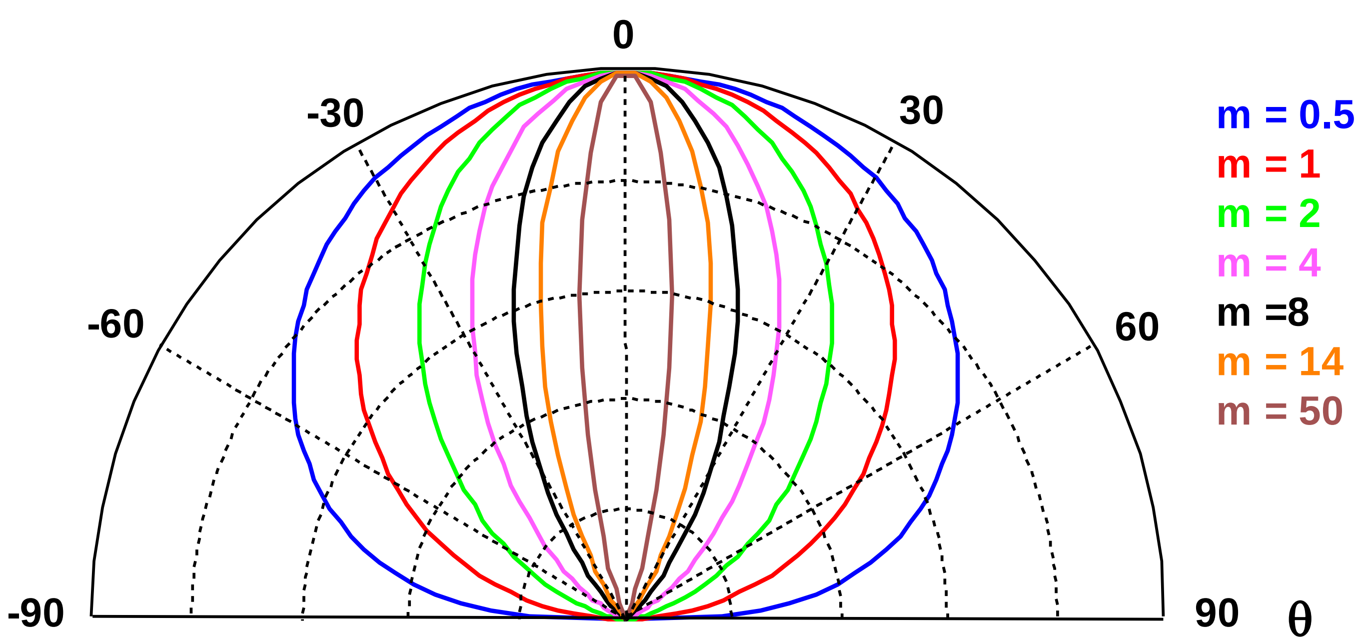


Sensitivity on Direction

- Acceptance angle of optical sensor
- Sensitivity of the response on the incidence angle
- Empirical description: generalized cos-law

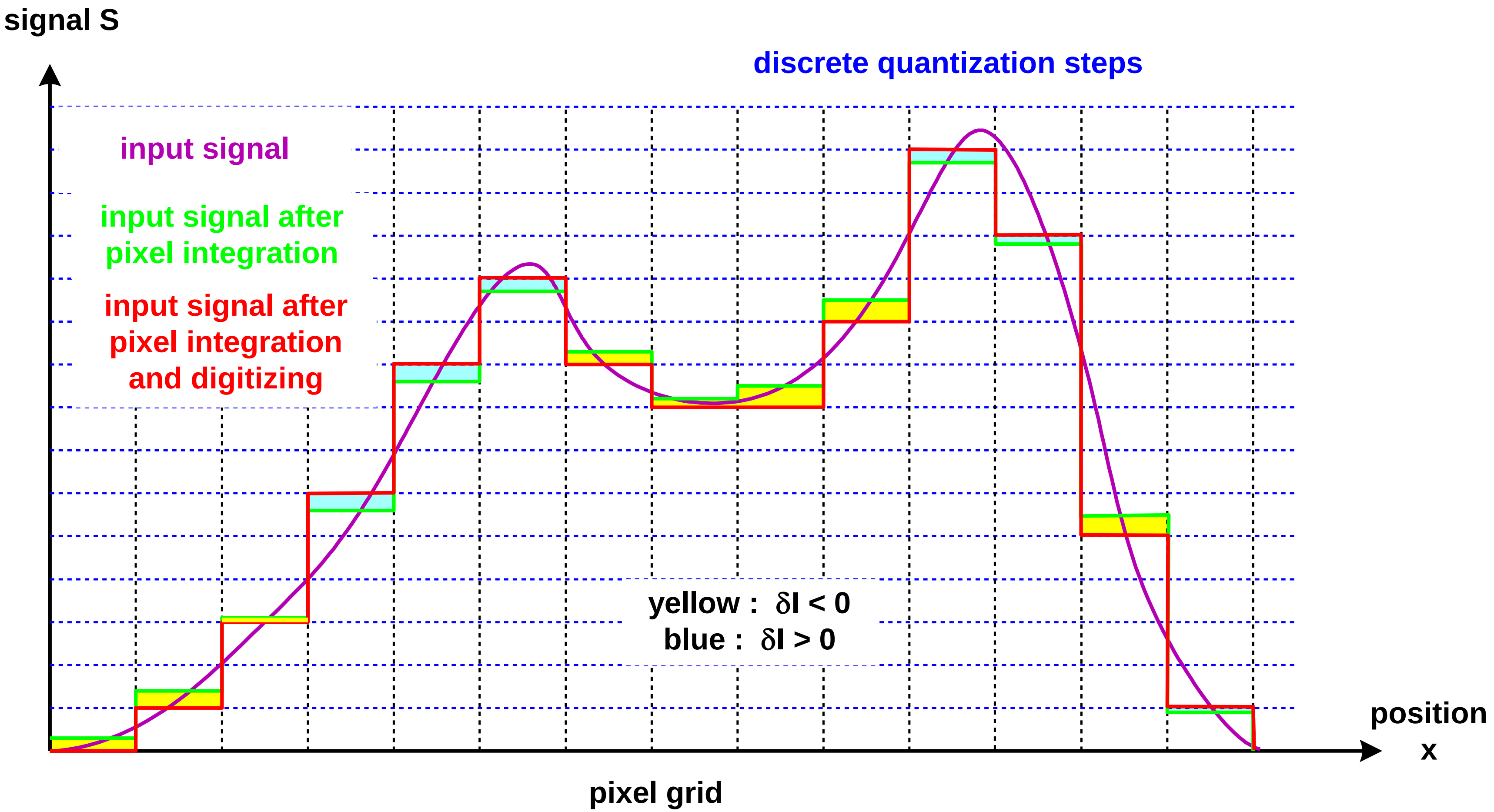
$$s(\theta) = s_0 \cdot \cos^m \theta$$

- Largest sensitivity for normal incidence



Digitization of the Signal

- Combined effect of spatial discretization and digitization (quantization)
- Averaging and rounding of signals per pixel
- Rounding corresponds to noise



Discretization of the Signal

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- Quantization of signal in intervals of finite size ΔI
- Typical powers of 2 are used
  8 bit corresponds to 256 value of the signal

$$M = 2^B = \frac{I_{\max}}{\Delta I}$$

- Rounding of real numbers is equivalent to signal noise

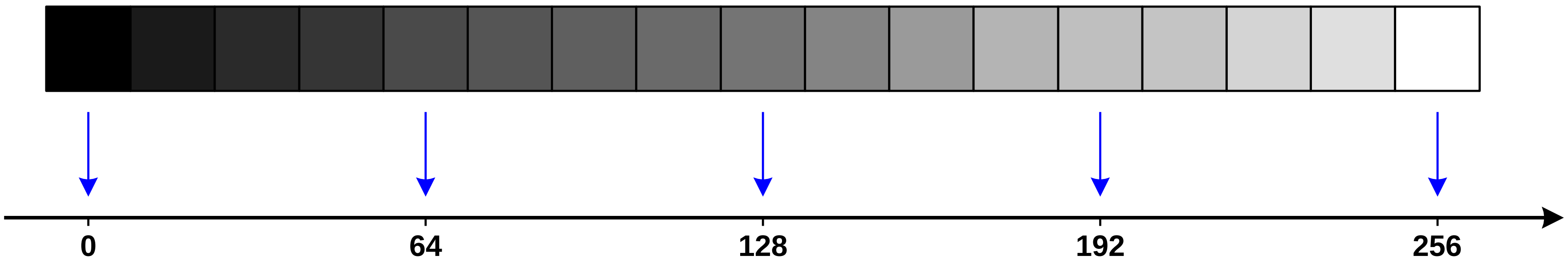
$$\frac{S}{N} = 6 \cdot B\,[dB]$$

- Noise equivalent power

$$P_{noise,quant} = k \cdot \frac{\Delta I^2}{12}$$

- Representation of discretized black-white image as gray levels

grey tone division



Characteristic Numbers of Sensors

- System model: sensor signal as function of measuring quantity
  ideal case: linear behavior
  sensitivity: slope

$$S = s \cdot a + b$$

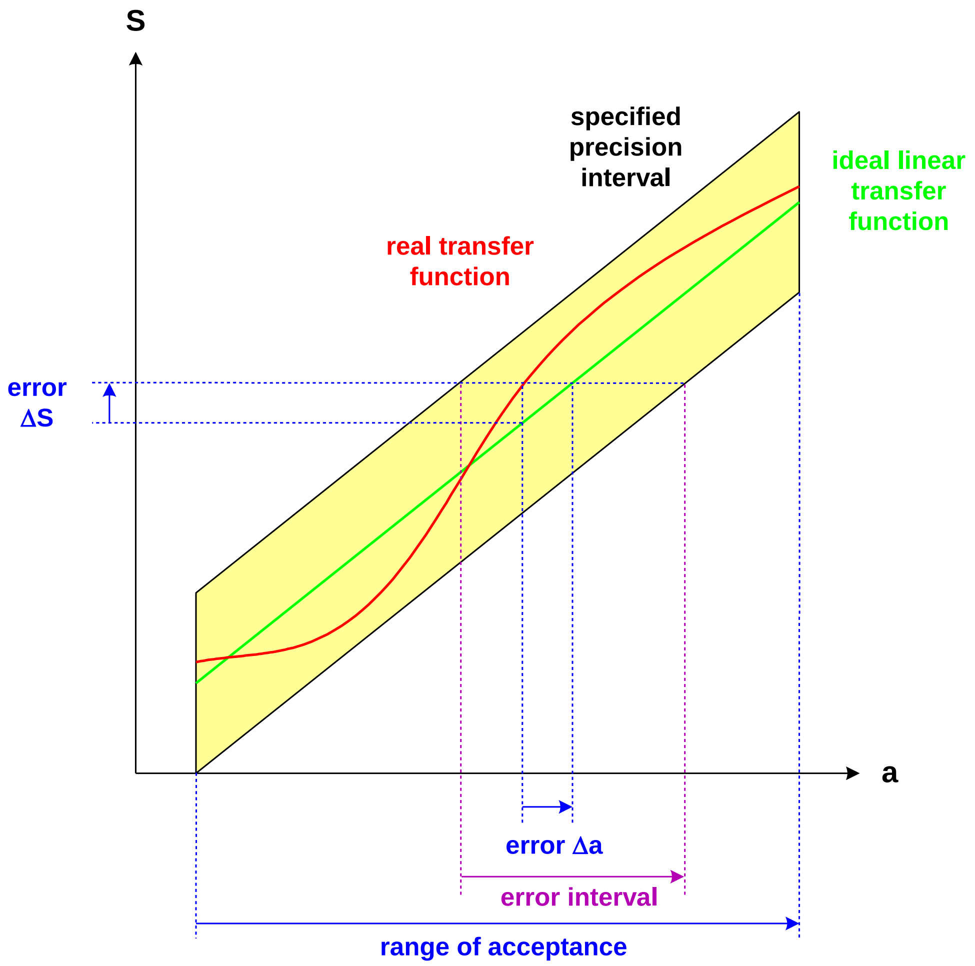
$$s = \left.\frac{dS(a)}{da}\right|_{a=a_o}$$

- Characteristic numbers of a sensor:
  1. sensitivity
  2. stability
  3. accuracy
  4. speed of response
  5. hysteresis
  6. life time
  7. cost
  8. size and weight
  9. spatial resolution
  10. linearity
  11. range of acceptance, dynamic range
  12. selectivity
  13. size of dead zones

Accuracy

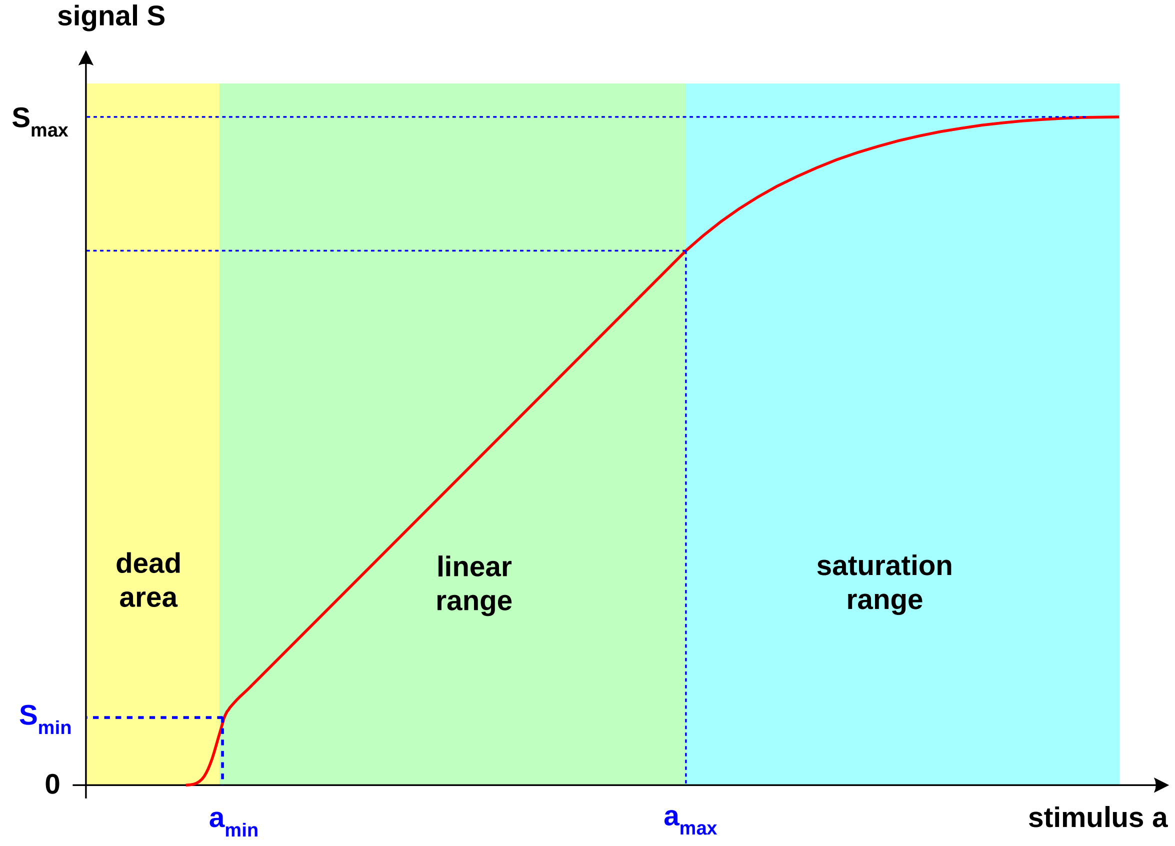
- Accuracy of a sensor:
  error of signal for a given input

- to be distinguished:
  1. calibration
  2. hysteresis
  3. reproduction
  4. sample scatter



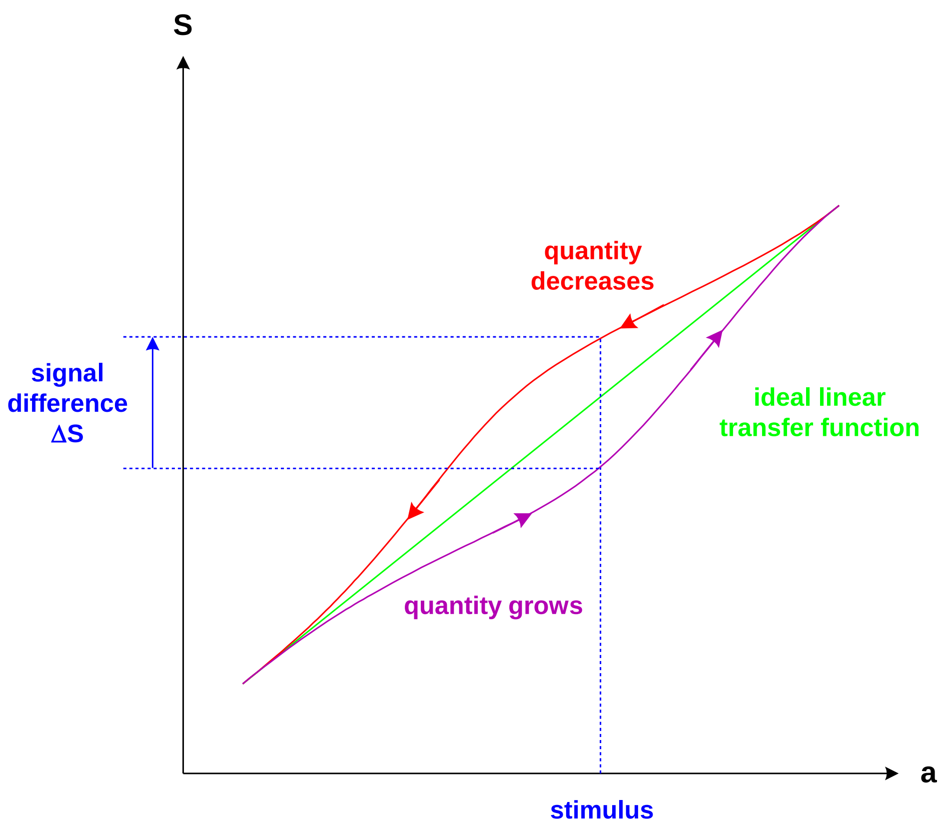
Dynamic Range

- Every sensor has a finite range of operation for the input stimulus
- Limitations:
  - upper limit: saturation
  - lower limit: noise



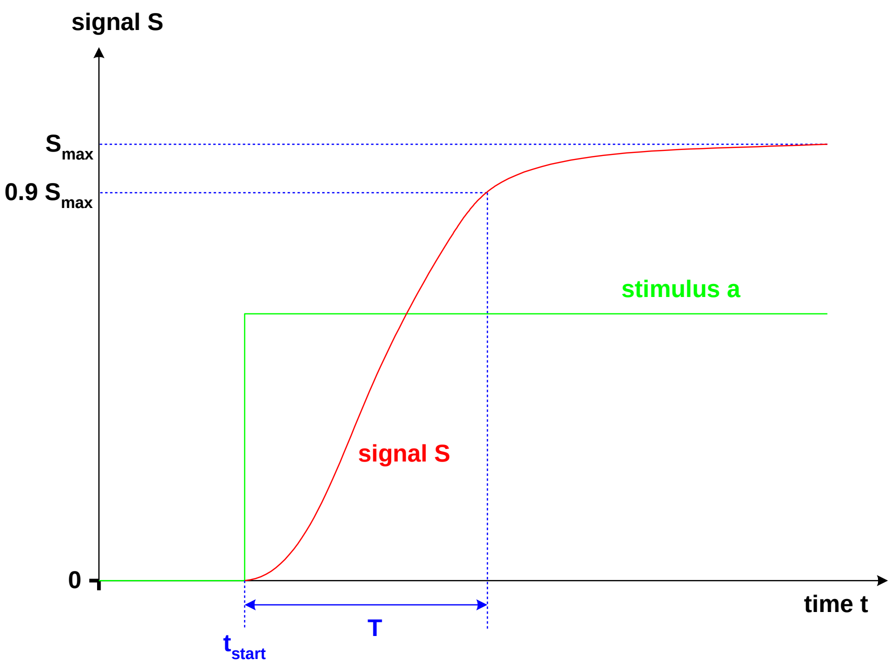
Hysteresis

Hysteresis:
the size of the signal depends on the fact, if the input is increasing / decreasing

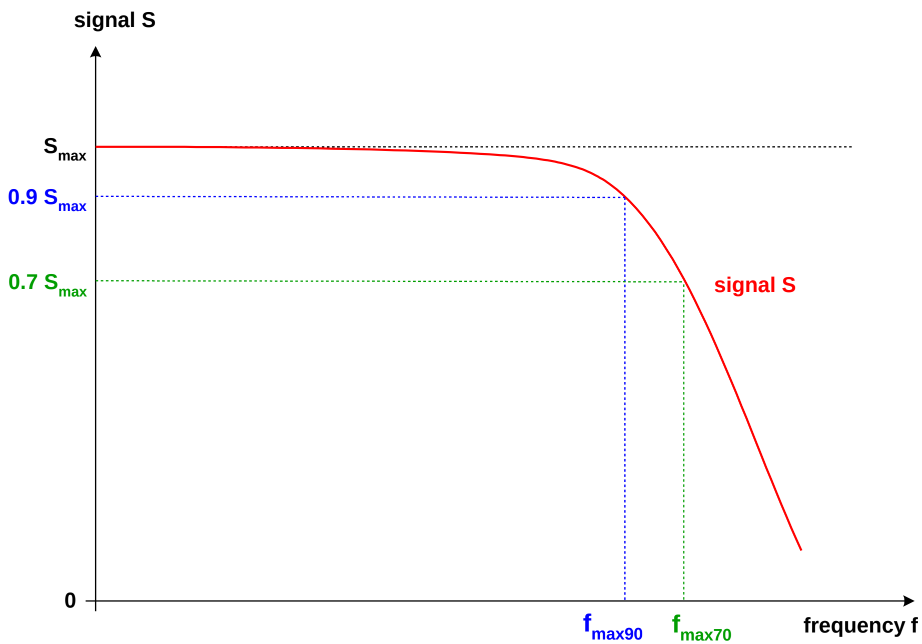


Time Response

- Removed input:
  - sensor reacts with a delay
  - switch-on curve with characteristic delay time



- Alternative description:
  - frequency response for periodic activation
  - maximum acceptance frequency



Time Response

- Step response:
  - usually oscillations
  - damping feasible