Berner Fachhochschule
Haute école spécialisée bernoise
Bern University of Applied Sciences

Introduction to Image Processing:

Image Acquisition

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Digital Image Acquisition: Excelent Resource

- **Stemmer Imaging:**
  - **Das Handbuch der Bildverarbeitung:**
  - http://www.stemmer-imaging.de/de/handbuch-der-bildverarbeitung/

Digital Image Acquisition

We will focus on visible light sensitive sensors:

- **CCD & CMOS Image Sensors**
  - **Optics**
  - **Image Sensor Types**
  - **Color Acquisition**
  - **Error Sources**
  - **Camera Interfaces**

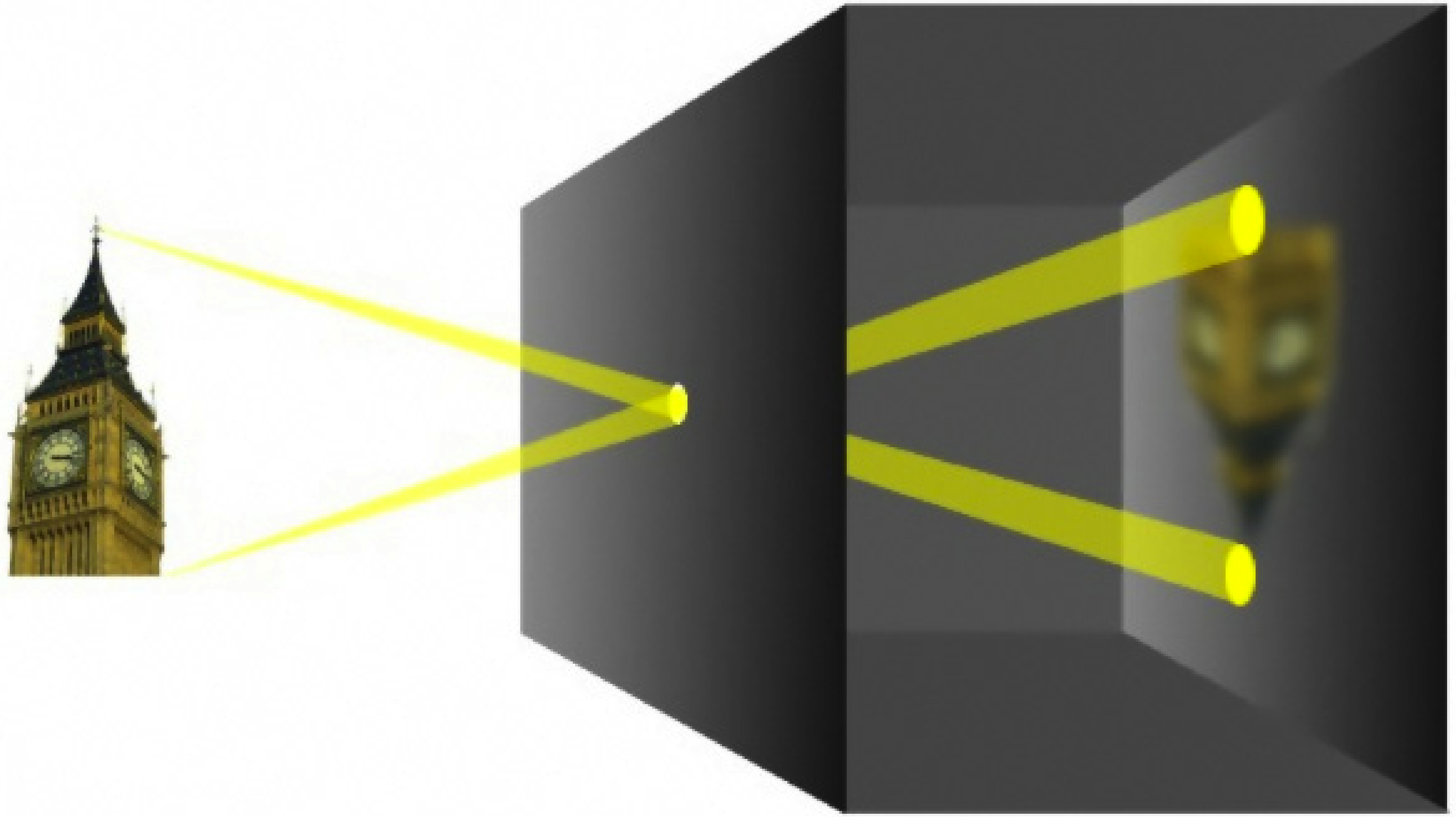
- X-Ray Imaging
- CT (Computer Tomography)
- PET (Positrone Emission Thomography)
- MRI (Magnetic Resonance Imaging)
- OCT (Optical Coherence Tomography
- Electron Mikroscope
- Transmission Electron Mikroscope
- Scanning Tunneling Microscope
- Ultrasound Imaging

Digital Image Acquisition: Optics: Camera Obsura

- **Perspective Projection** was first discovered by **Aristoteles** 350 b.C.
- The **camera obscura** was first used as a **drawing aid**.
- But with tiny hole you get only **very dark projections**

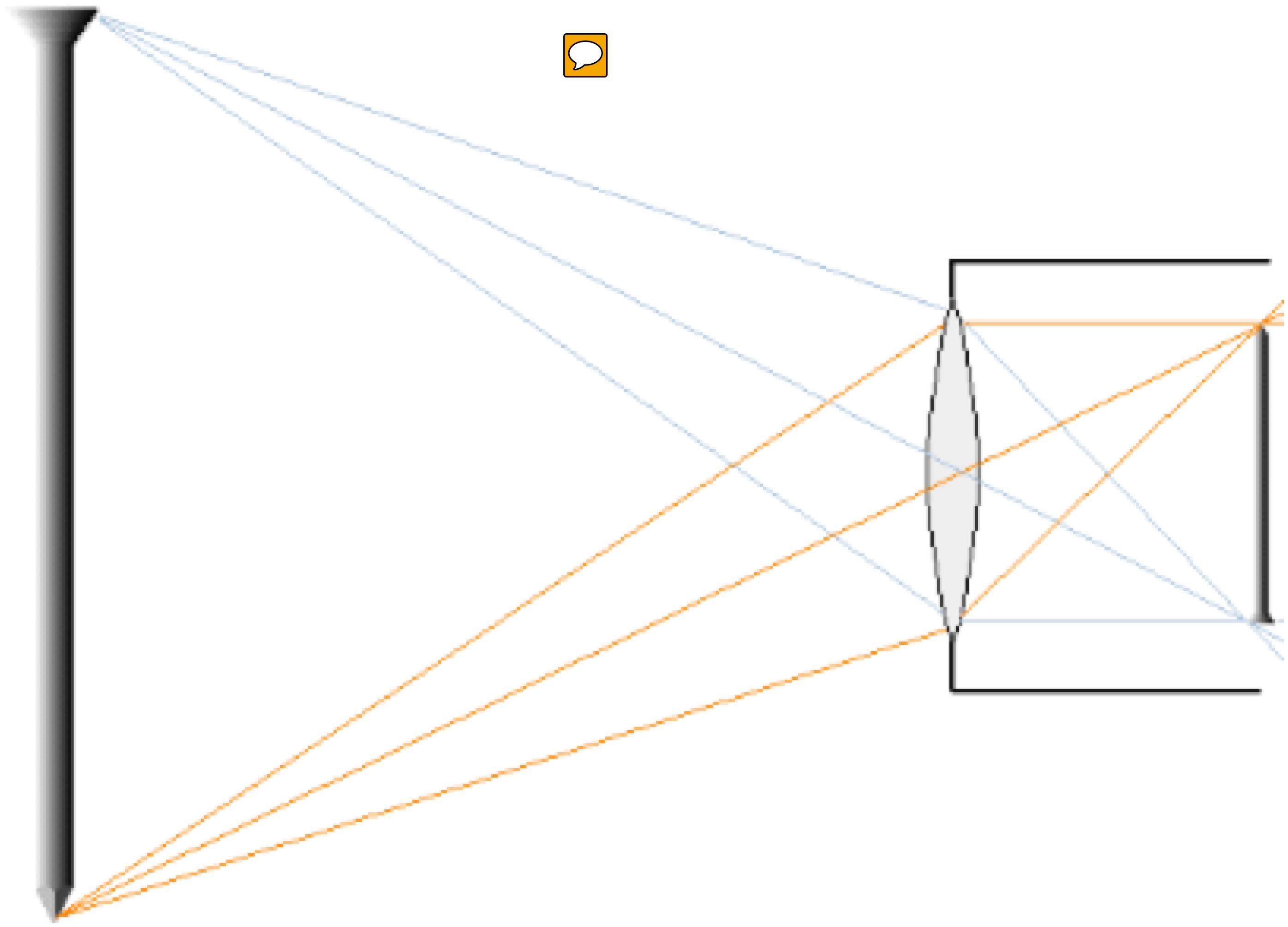
Digital Image Acquisition: Optics: Camera Obsura

- With a **camera obscura** you get only sharp images with a **tiny pin hole**:
- With a wider pin hole the image gets **blury**:



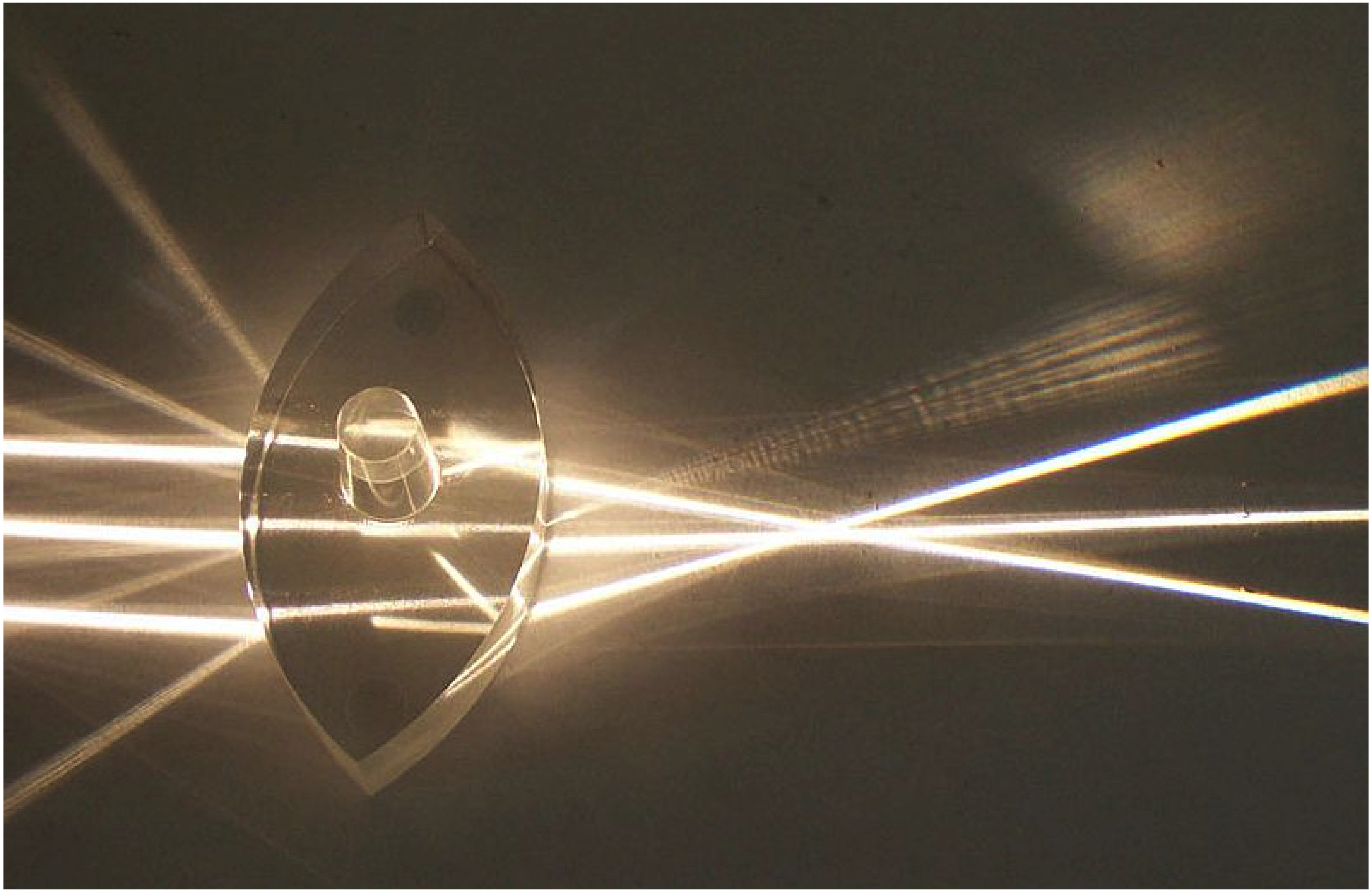
Digital Image Acquisition: Optics: Lens

- The lens had to be invented to refocus the image:



Digital Image Acquisition: Optics: Lens Properties

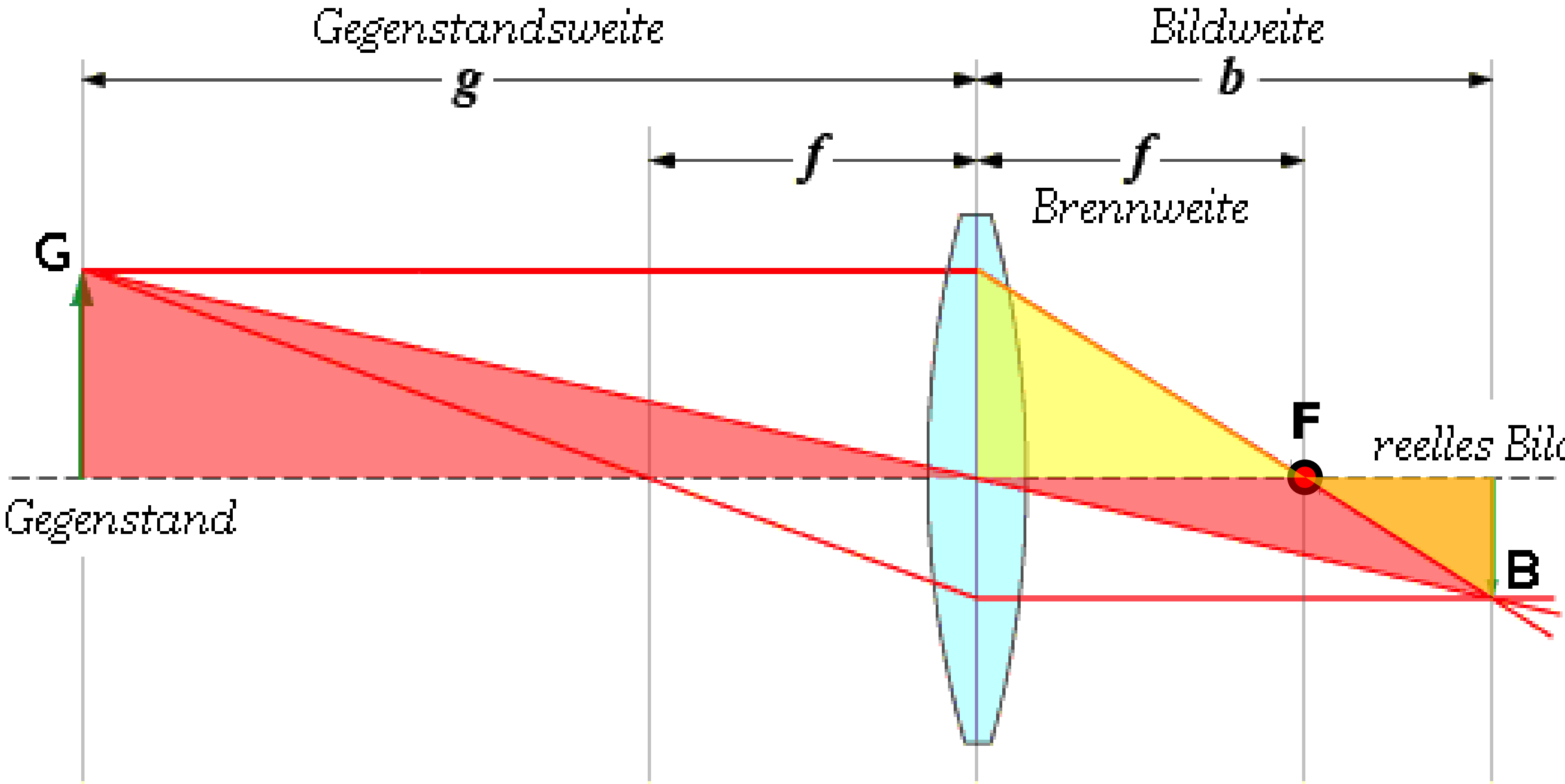
- **Focal point F** where parallel incomming rays meet after the lens
- **Focal length f** ist the distance from **F** to the the **optical plane** of the lens



Digital Image Acquisition: Optics: Lens Properties

- **Reproduction scale (Abbildungsmassstab):** $$A = \frac{B}{G} = \frac{b}{g}$$

- **Intercept Theorem (Strahlensatz):** $$\frac{B}{G} = \frac{b}{g} = \frac{b-f}{f}$$



Digital Image Acquisition: Optics: Thin Lens Equation

- With tranformation we get the **thin lens equation:**
- Nice but not really useful.

$$\boxed{\frac{1}{b}+\frac{1}{g}=\frac{1}{f}}$$

- Deduced from it:

  Focal length f from given **sensor size B** and **object distance G:**

$$f=\frac{g}{\frac{G}{B}+1}$$

- **Example**: Which focal length f is needed with a 1/2 inch sensor (B=6.4mm) camera to capture a 150mm object in a distance of 300mm?

  f = 300/(150/6.4+1) = 12.28mm

Digital Image Acquisition: Optics: Thin Lens Equation

- With tranformation we get the **thin lens equation:**
- Nice but not really useful.

$$\boxed{\frac{1}{b}+\frac{1}{g}=\frac{1}{f}}$$

- Deduced from it:

  Object distance G from given **focal lenght f** and **sensor size B**:

$$g=f\cdot\left(\frac{G}{B}+1\right)$$

- **Example**: How far away from a 150mm object must a camera be with a 1/2 inch sensor (B=6.4mm) and 12mm lens (f)?

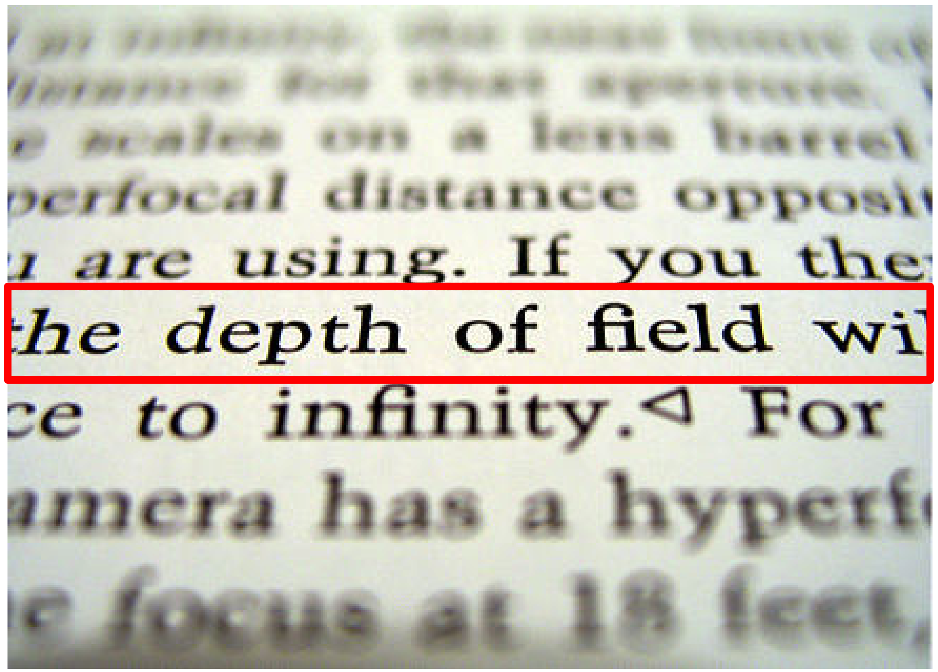
  g = 12·(150/6.4+1) = 293.25mm

Digital Image Acquisition: Optics: Lens Properties

- With the **aperture** you set the opening of the **diaphragm** of the lens
- The aperture is defined as focal depth f over diameter D: $aperture = \frac{f}{D}$
- It is often writen as **f/aperture**.
- Standard f-numbers are: 1, 1.4, 2.8, 4, 5.6, 8, 11, 22
- Every bigger aperture reduces the light **50%**

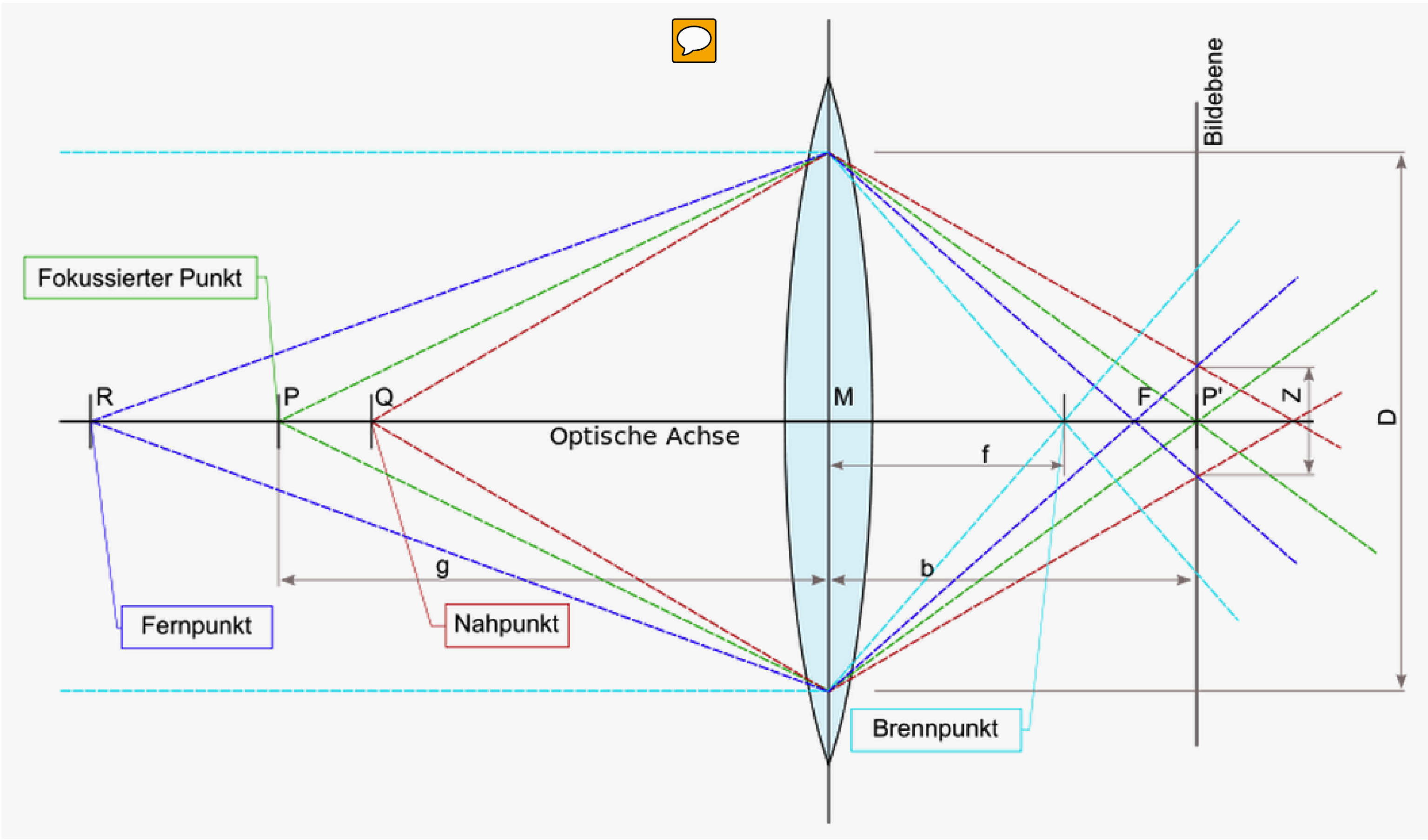
Digital Image Acquisition: Optics: Lens Properties

- The **depth of field** is the distance between the **nearest** and **farest** sharp point.
- Better lenses indicate this distance depending on the **aperture**.



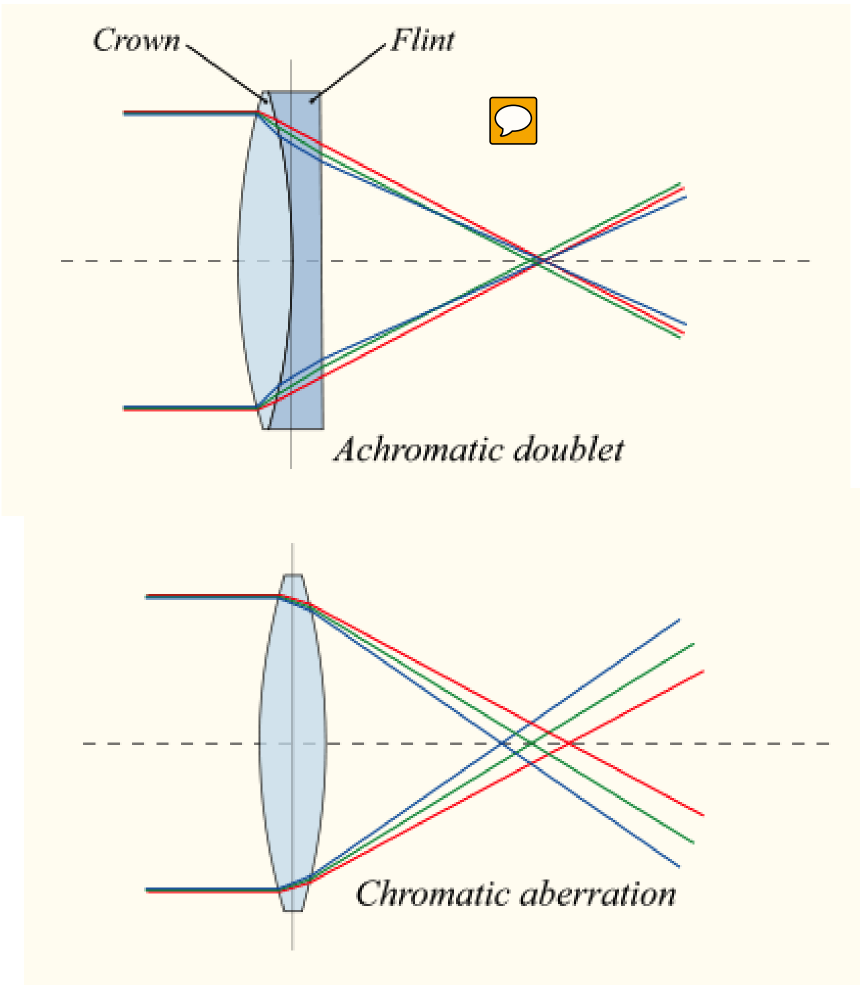
Digital Image Acquisition: Optics: Lens Properties

- The **depth of field** is the distance between the **nearest** (**Q**) and **farest** sharp point (**R**) that produces a **circle of confusion** with a diameter (**Z**).
- See Wikipedia for the precise formulas.
- An aproximation is 1/reproduction scale: $DOF \approx \frac{1}{A} = \frac{G}{B} = \frac{g}{b}$



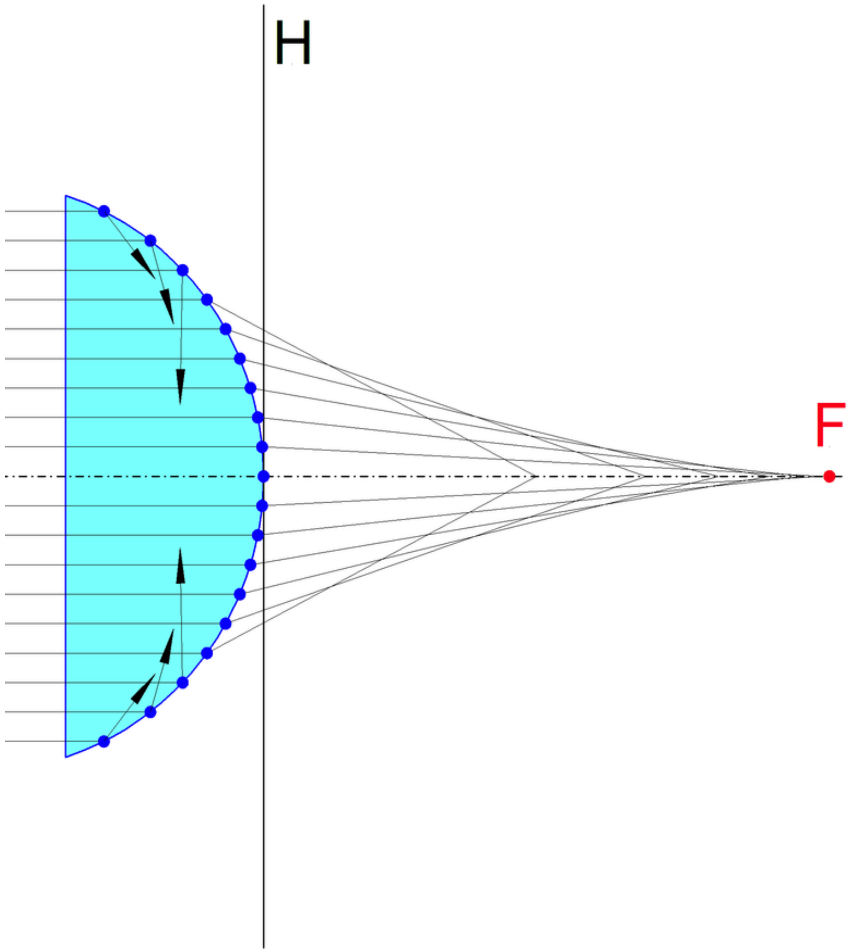
Digital Image Acquisition: Optics: Aberrations

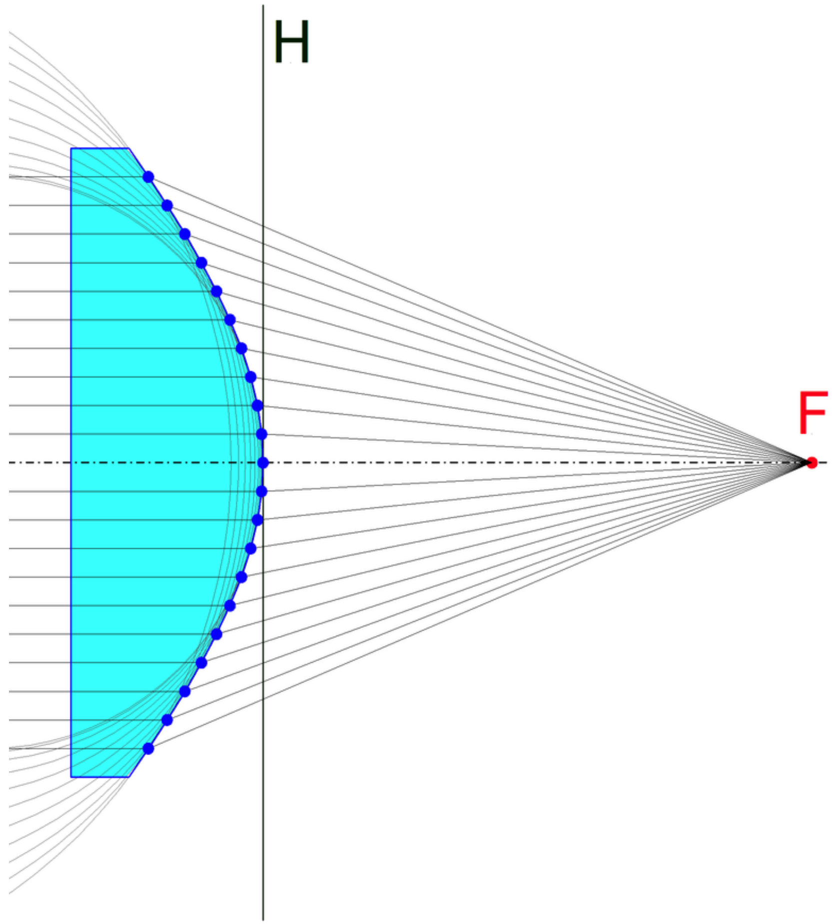
- **Chromatic aberrations** are caused by the different refraction angles of the different wave length.
- It can be corrected with achromatic lens combinations



Digital Image Acquisition: Optics: Aberrations

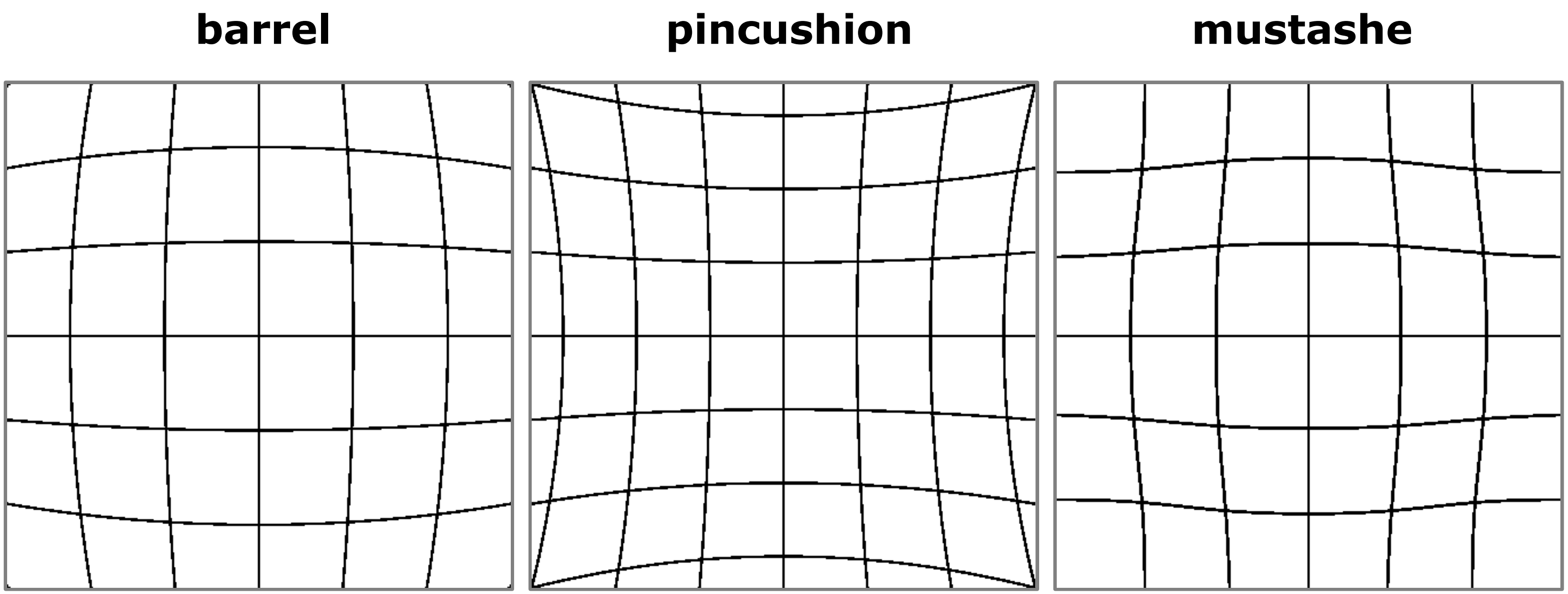
- **Spherical aberrations** are caused by the spherical shape of the lens.
- Spherical shape are easy to produce.
- For a **perfect focal point** the lens has to habe an **aspherical shape**:





Digital Image Acquisition: Optics: Aberrations

- **Distortion** means that rectangular structures are not anymore projected rectangular.
- The wider the view angle the stronger will be the distortion.
- **Classic distortions:**

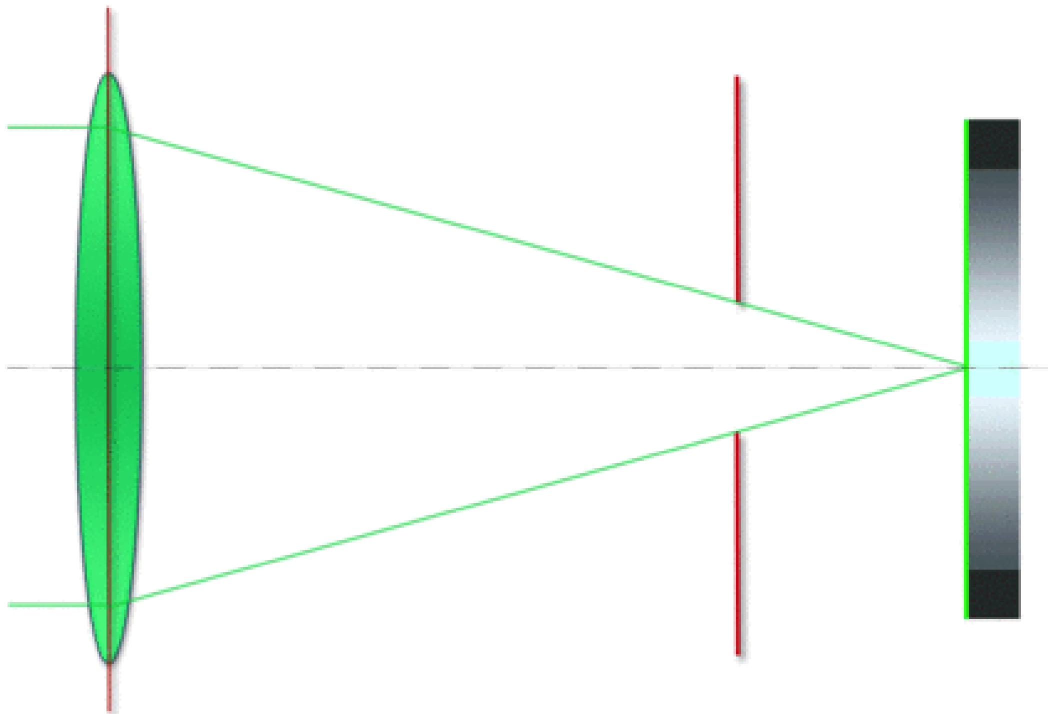


Digital Image Acquisition: Optics: Aberrations

- **Vingetting** stands for any reduction of brightness from the center away.

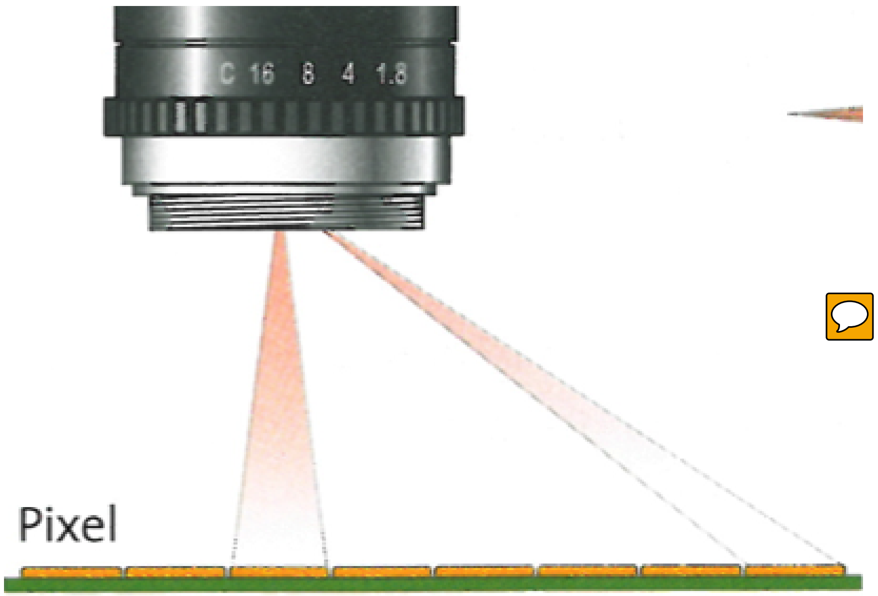
Digital Image Acquisition: Optics: Aberrations

- **Vingetting** can be caused:
  - **optically** and **mechanically** by the **diaphragm** and **lens housing**.



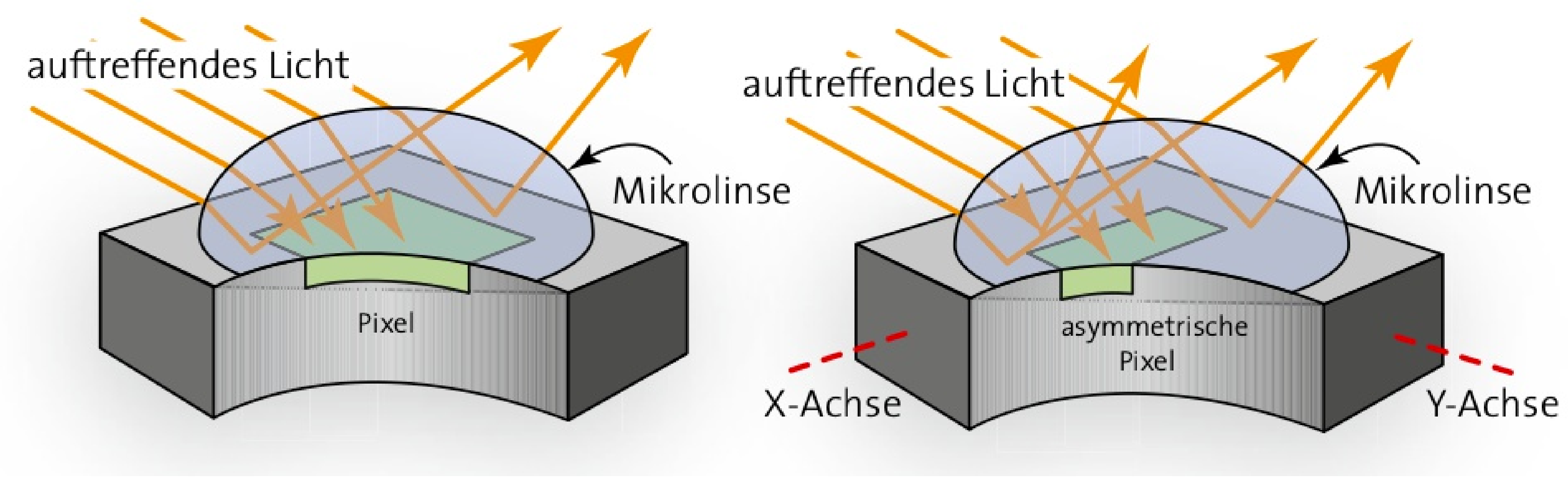
Digital Image Acquisition: Optics: Aberrations

- **Vingetting** can be caused:
  - optically and mechanically by the diaphragm and lens housing.
  - **naturally** by the **Cos^4 vignetting**:



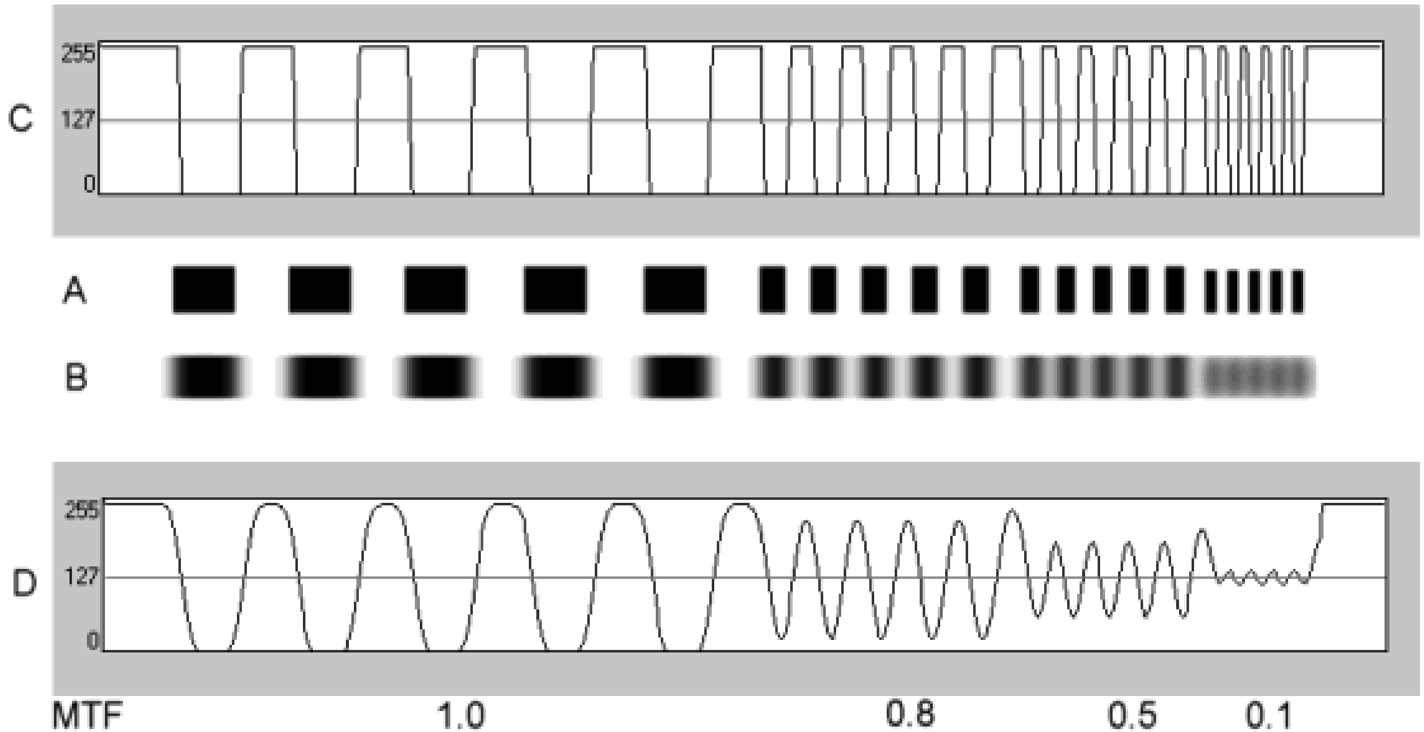
Digital Image Acquisition: Optics: Aberrations

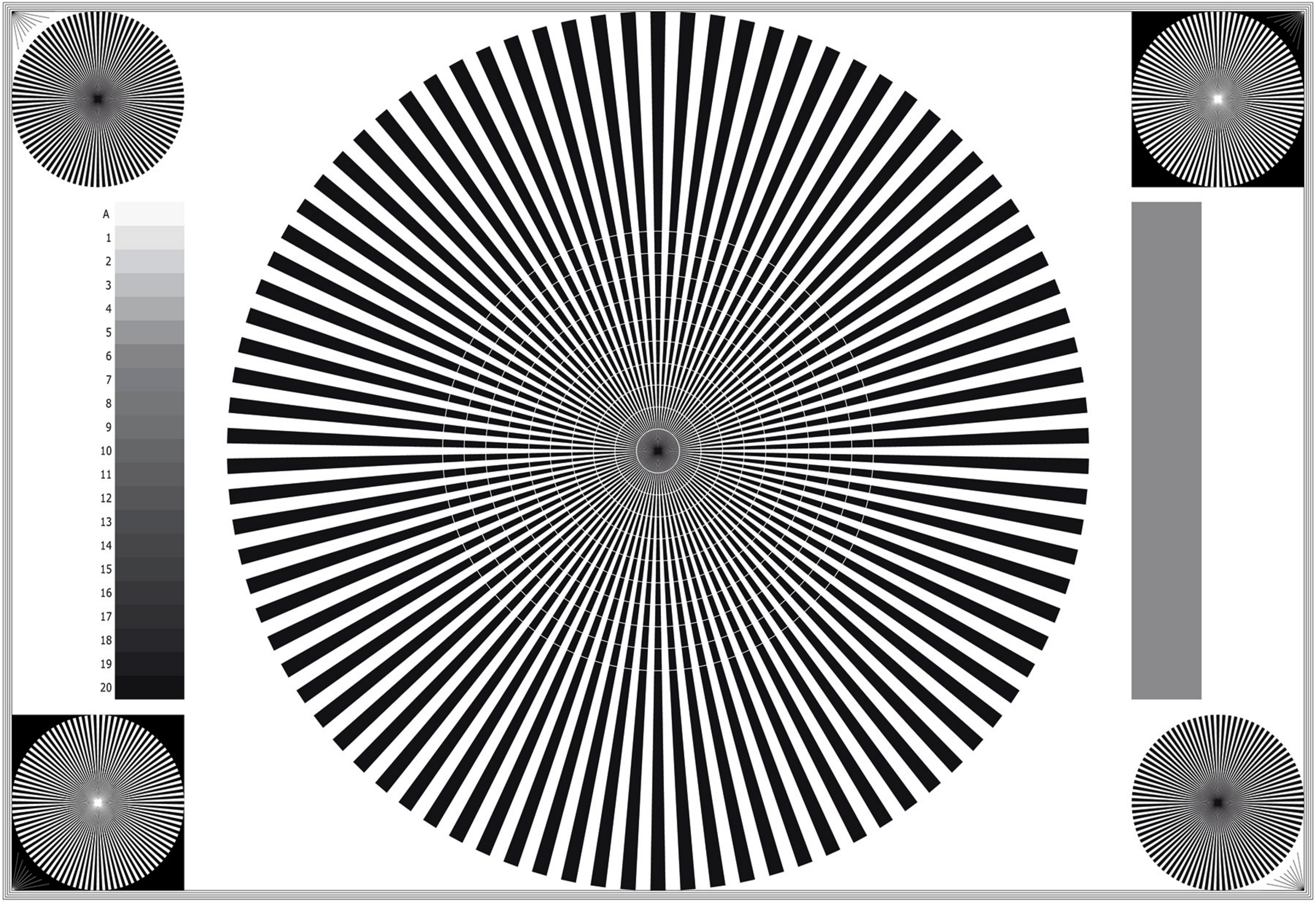
- **Vingetting** can be caused:
  - optically and mechanically by the diaphragm and lens housing.
  - naturally by the Cos^4 vignetting.
  - by **asymmetrical pixels**:



Digital Image Acquisition: Optics: Aberrations

- The **Modulation Transfer Function (MTF)** describes the reproduction quality of a lens.
- B/W lines pattern that get more and more thinner are depicted.
- The MTF is measured in lines per mm that can be reproduced befor the contrast is zero.
- There is no standard for the MTF calculation.





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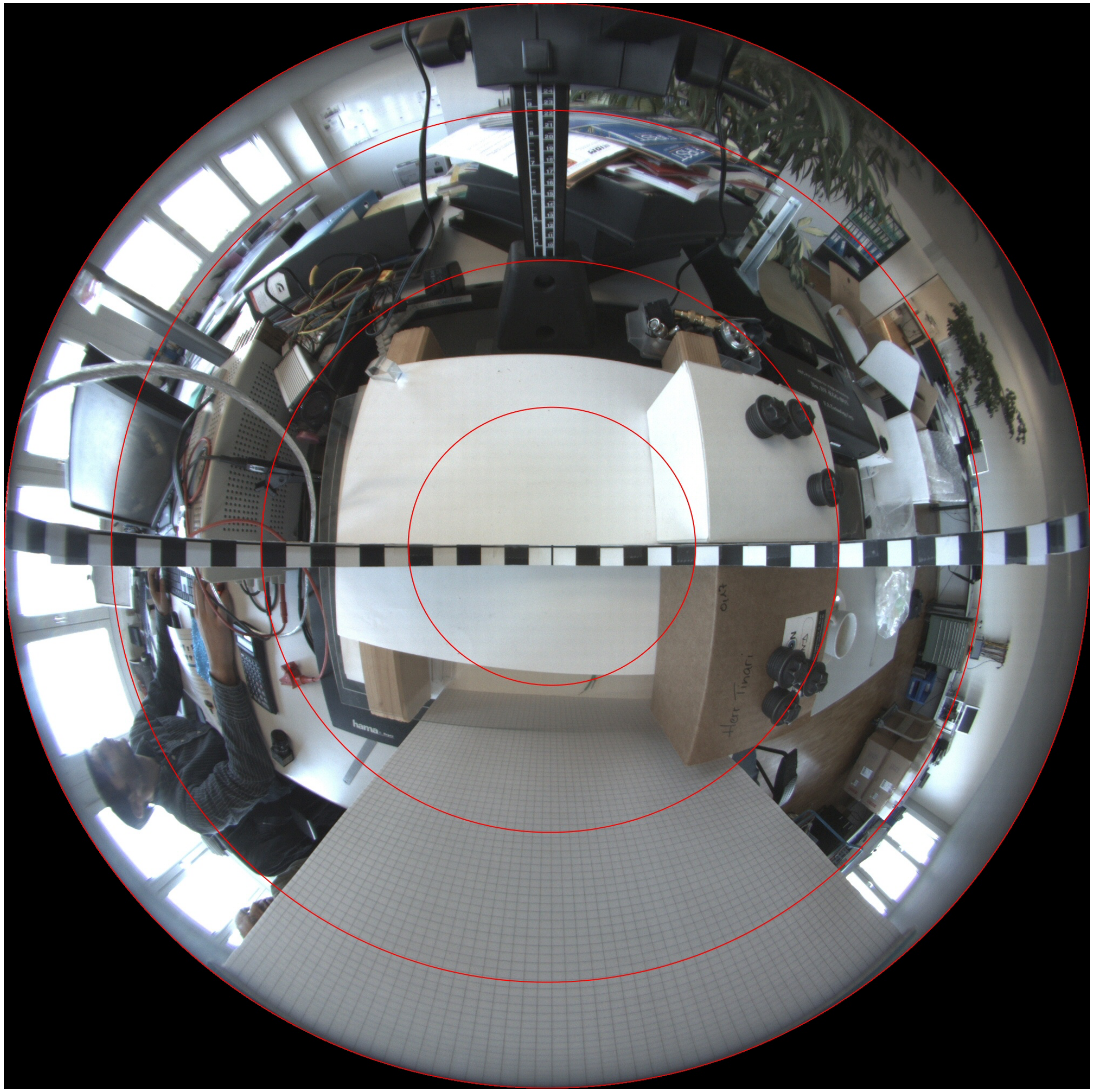
Digital Image Acquisition: Optics: Lens Types

- **Mono focal lenses:**
  - Standard lenses: MTF: 70-90 lp/mm
  - High precision lenses: MTF: 120 lp/mm

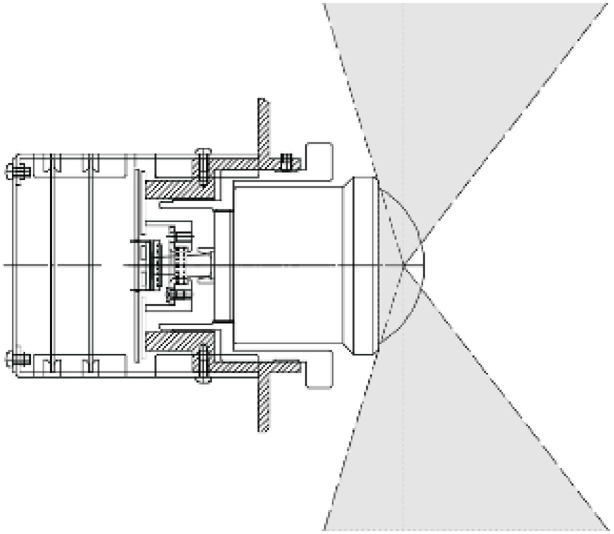
Digital Image Acquisition: Optics: Lens Types

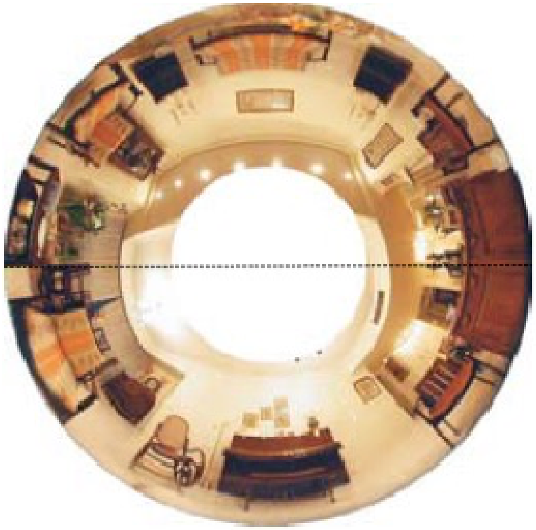
- **Mono focal Lenses:**
  - **Fisheye lenses** can have a view angle up to 240°



Digital Image Acquisition: Optics: Lens Types

- **Mono focal Lenses:**
  - **Special lenses** such a this Sony lens have view angles from -17° to +38°



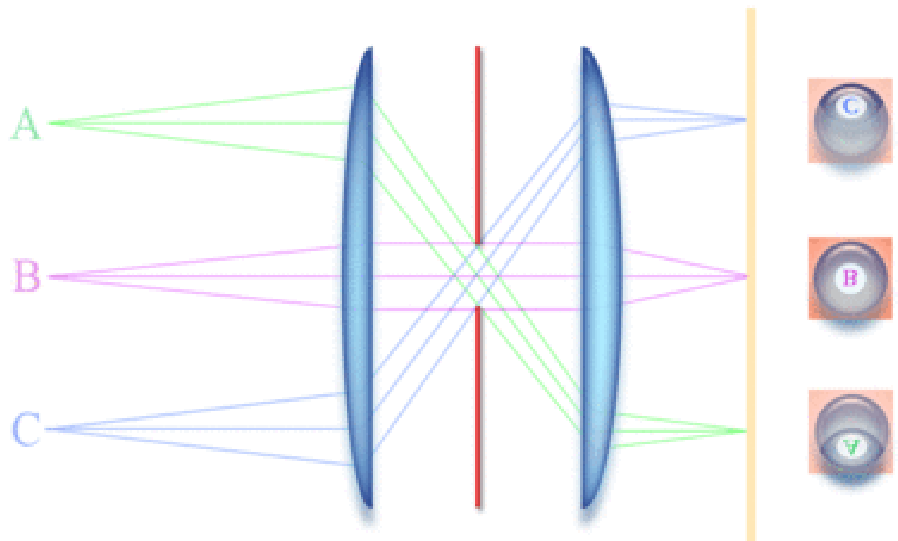


Digital Image Acquisition: Optics: Lens Types

- Mono focal lenses:
- **Vario focal lenses (zoom lenses)** are rather rarely used in machine vision:

Digital Image Acquisition: Optics: Lens Types

- Mono focal lenses:
- Vario focal lenses (zoom lenses)
- **Telecentric lenses** provide orthographic projection upto a certain distance:



Digital Image Acquisition: Optics: Lens Types

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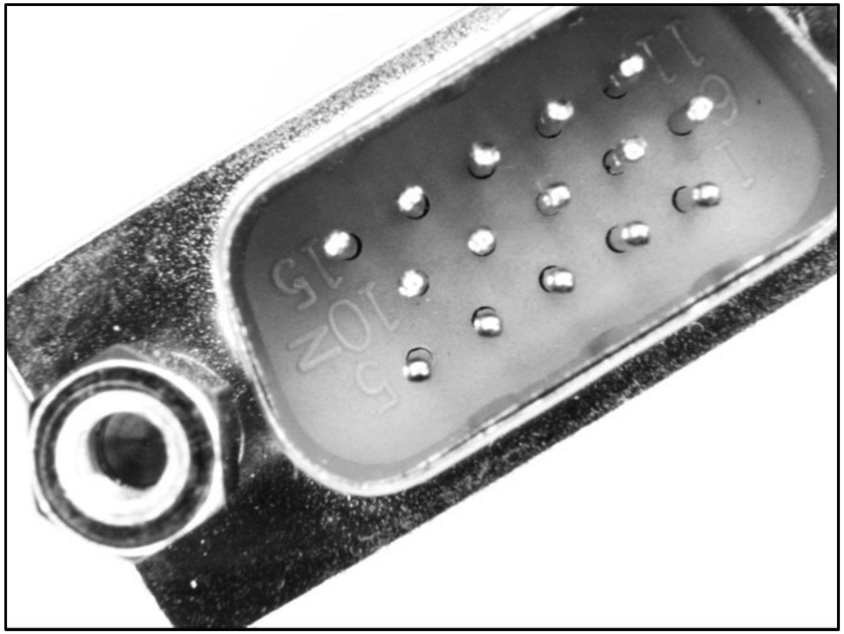
- Vario focal lenses (zoom lenses)
- **Telecentric lenses** provide orthographic projection upto a certain distance:

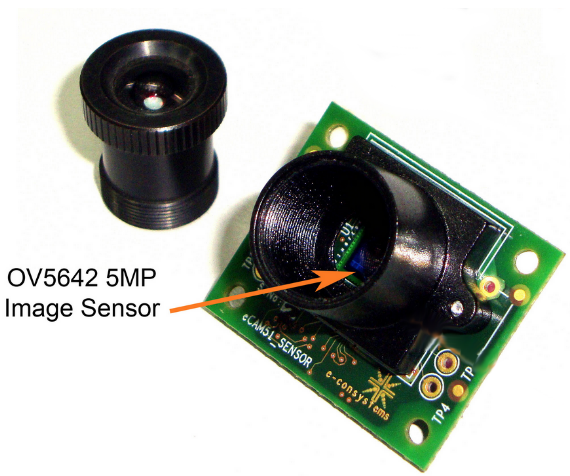
Digital Image Acquisition: Optics: Lens Types

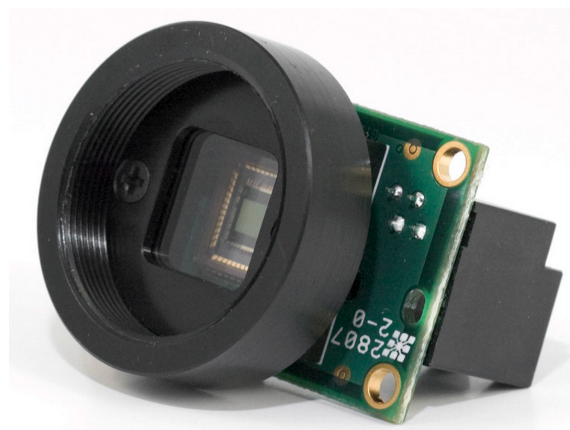
- Mono focal lenses:
- Vario focal lenses (zoom lenses)
- **Telecentric lenses** provide orthographic projection upto a certain distance.
  - They can be used perspectively undistorted views:



Digital Image Acquisition: Optics: Lens Mount

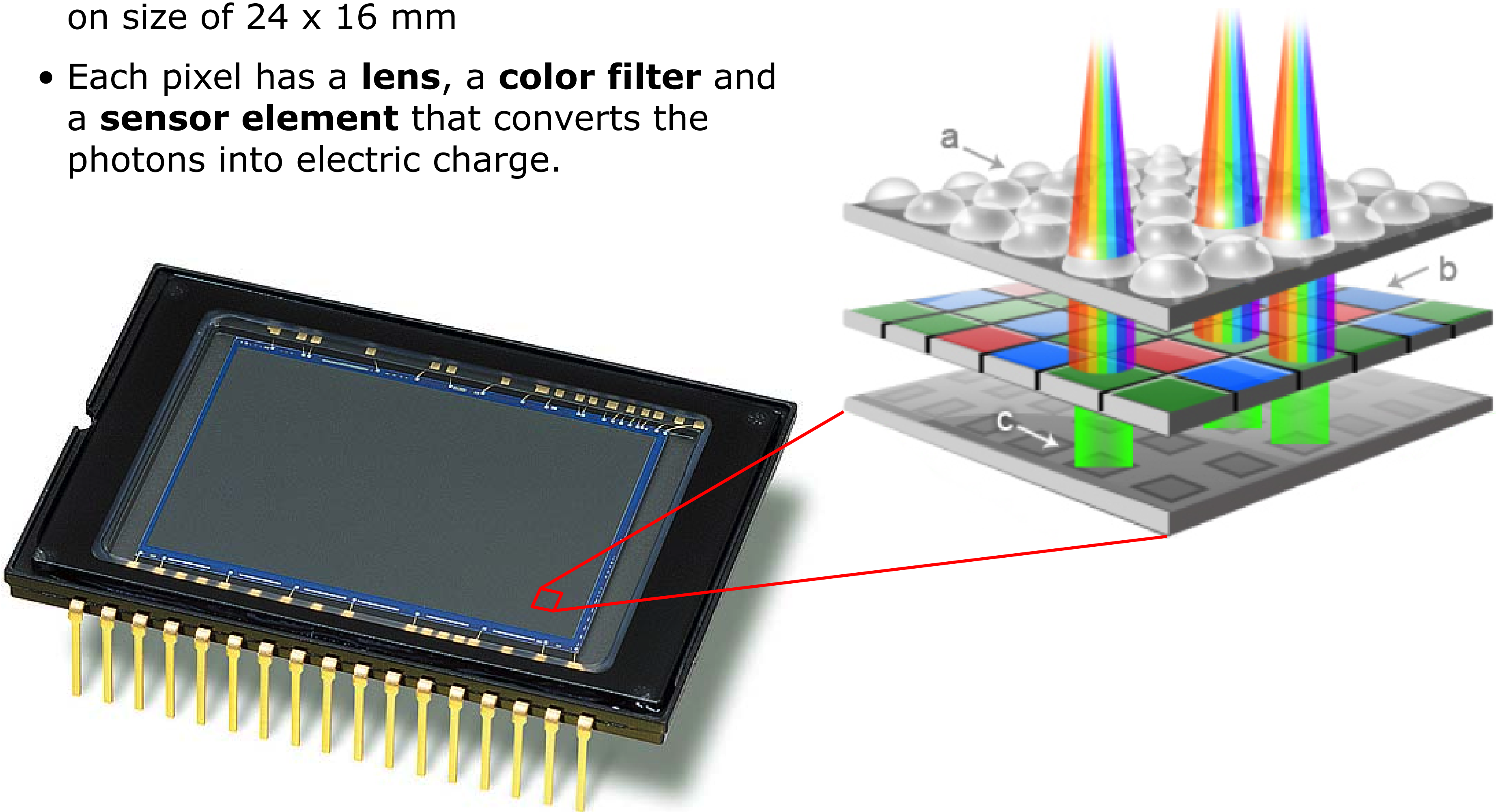
- **S-Mount**: M12x0.5-thread (12mm Gewinde) is used for board cameras.
- **C-Mount**: Das 1''x32 TPI thread (1''=1 Zoll=2.54cm mit 1/32 Steigung) is the most used mount for machine vision cameras. Deapth of the sensor: **17.5mm**
- **CS-Mount**: Same as C-mount but with a sensor depth of **12.5mm** only.
- **F-Mount**: This mount is the original mount of Nikon cameras and used only for very large sensors.





Digital Image Acquisition: Image Sensors

- **An image sensor converts light into an electric signal.**
- The following color sensor of a Nikon D40 has 3000 x 2000 pixels (picture elements) on size of 24 x 16 mm
- Each pixel has a **lens**, a **color filter** and a **sensor element** that converts the photons into electric charge.



Digital Image Acquisition: Image Sensors

- An image sensor size are **named in inches** (1'' = 25.5mm)
- The names do not correspond to the physical size of the sensors.
- Classis sensor size for machine vision cameras are:

Sensor size & resolution

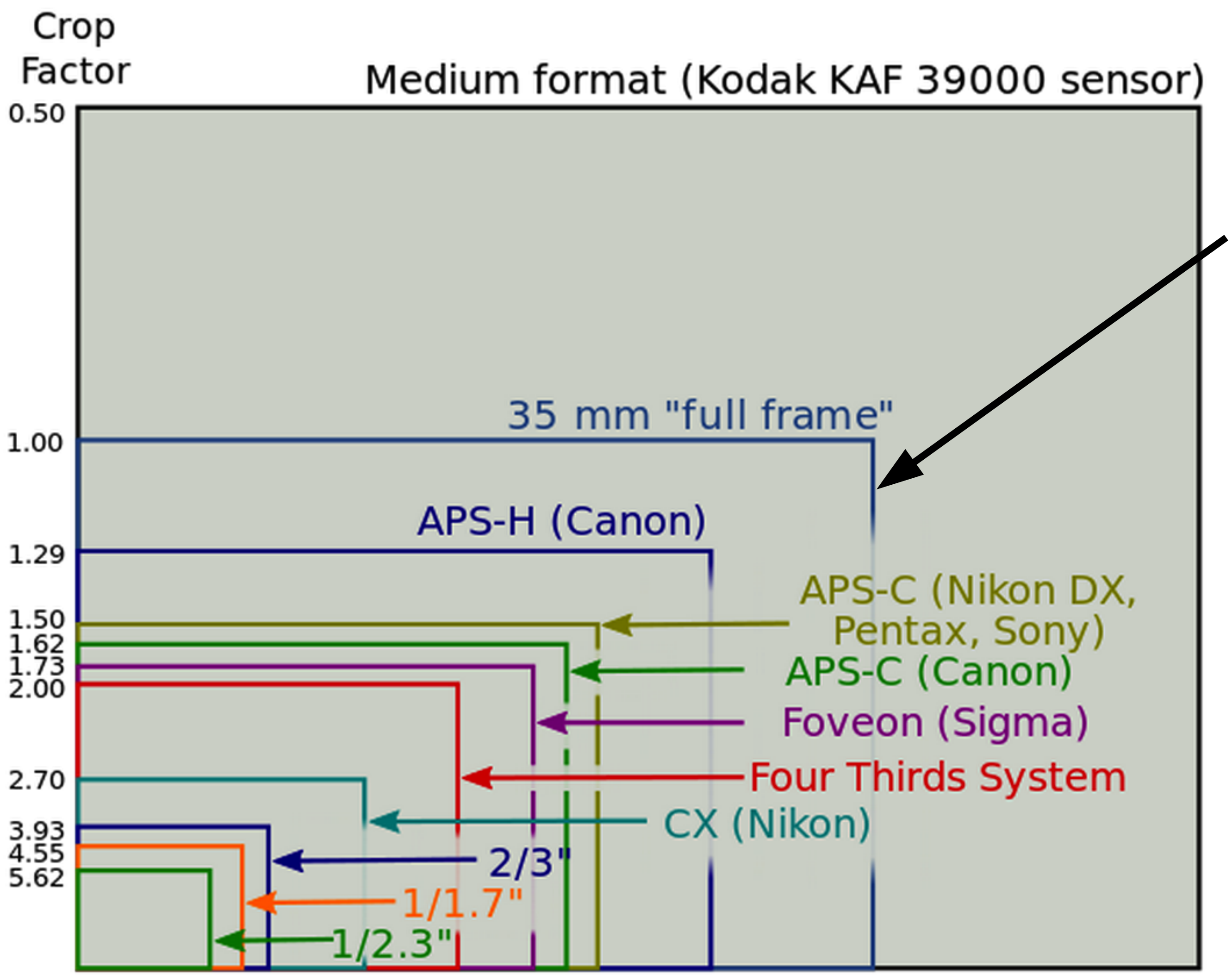
Resolution:	VGA	PAL	XGA	SXGA	2 MP	5MP
Width (px):	640	768	1024	1280	1628	2588
Height (px):	480	576	768	960	1236	1958
No. of pix.:	307'200	442'368	786'432	1'228'800	2'012'208	5'067'304

Sensor	Width (mm)	Height (mm)	Diag. (mm)	Pix.(μm)	Pix.(μm)	Pix.(μm)	Pix.(μm)	Pix.(μm)	Pix.(μm)
1/4"	3.65	2.74	4.56	5.7	4.8	3.6	2.9	**2.2**	**1.4**
1/3"	4.80	3.60	6.00	7.5	6.3	4.7	3.8	2.9	**1.9**
1/2"	6.40	4.80	8.00	10.0	8.3	6.3	5.0	3.9	**2.5**
2/3"	8.80	6.60	11.00	13.8	11.5	8.6	6.9	5.4	3.4
1"	12.70	9.50	15.86	19.8	16.5	12.4	9.9	7.8	4.9

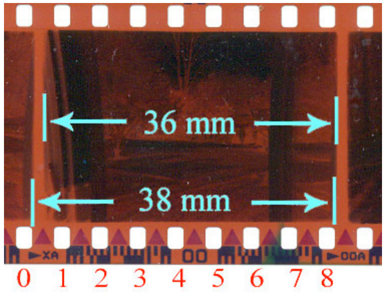
- The human eye has about 150'000 cones per mm^2 in the fovea.
  The human cone „pixel“ size is 2.6 μm or 0.0026 mm
- Sensor are not automatically better with a higher resolution!
- The smaller the pixel, the higher will be the noise!

Digital Image Acquisition: Image Sensors

- Sensors for **consumer photo cameras** are different:

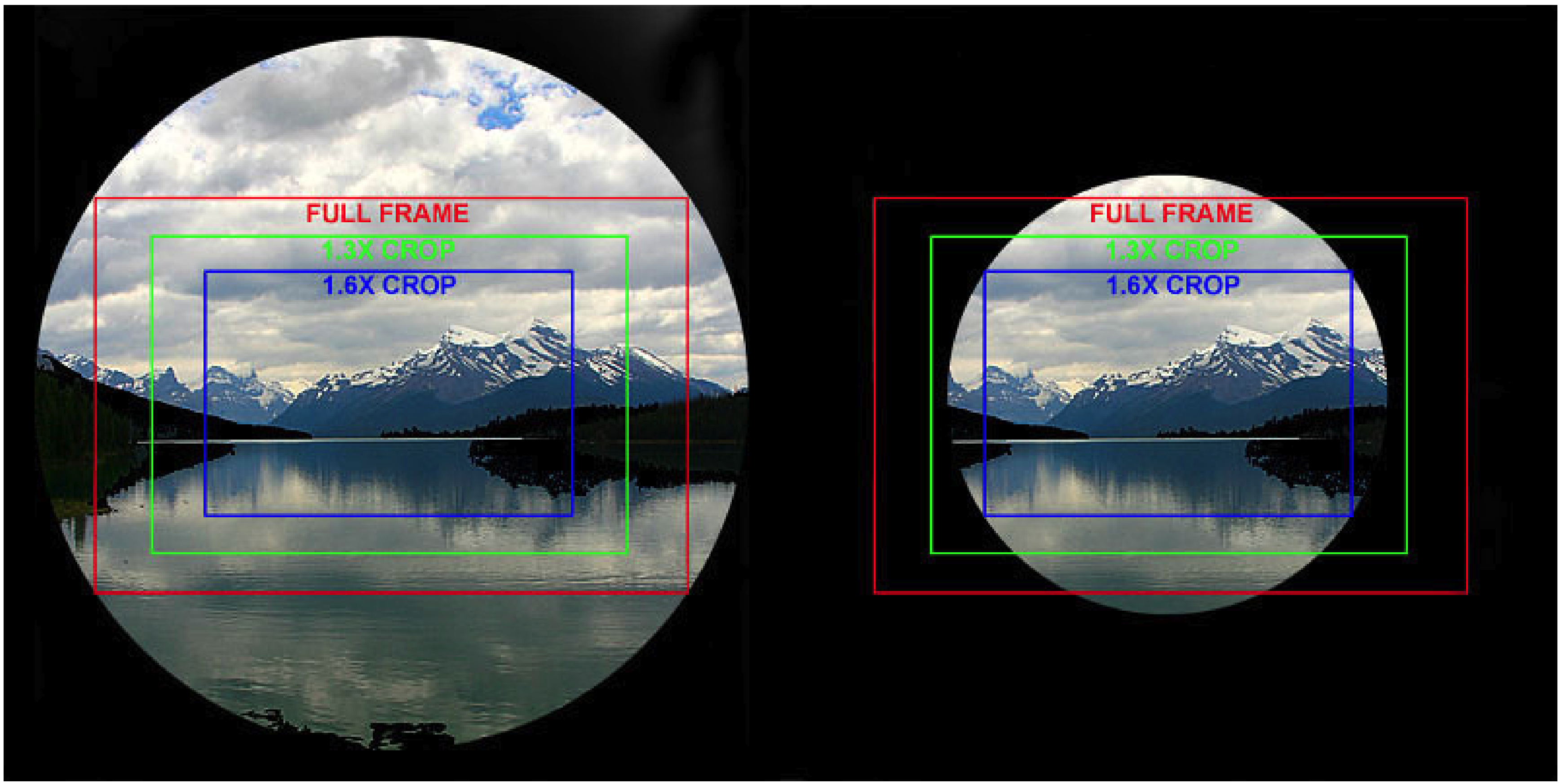


36×24mm negative film introduced by Oskar Barnack for the Leica camera



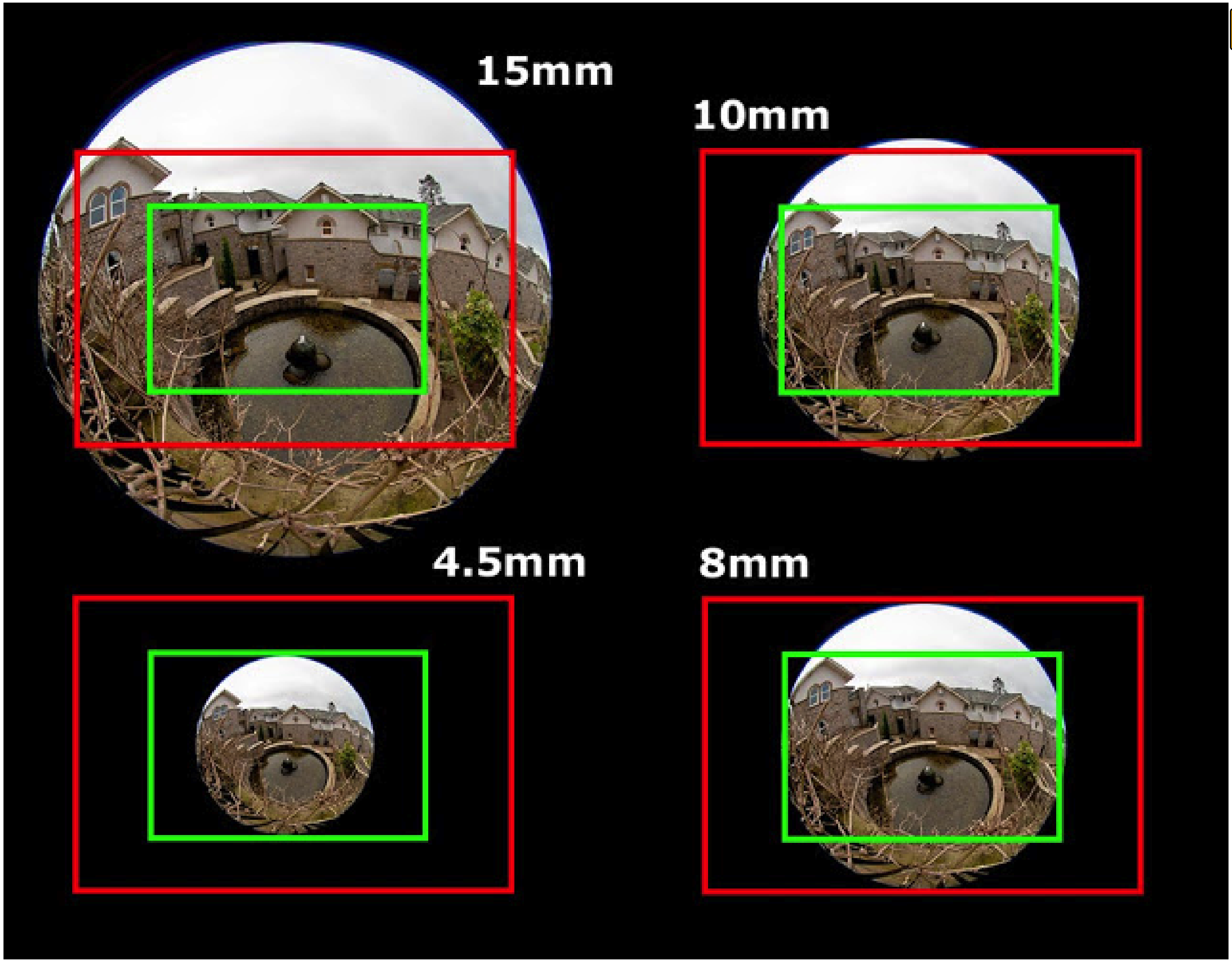
Digital Image Acquisition: Optics: Lens Mount

- You have to be carefull about the lenses **crop factor**.
- For DSLR Canon has e.g. 3 different lens types with different crop factors
- Be aware of **lens vingetting** at full frame in circle placement.



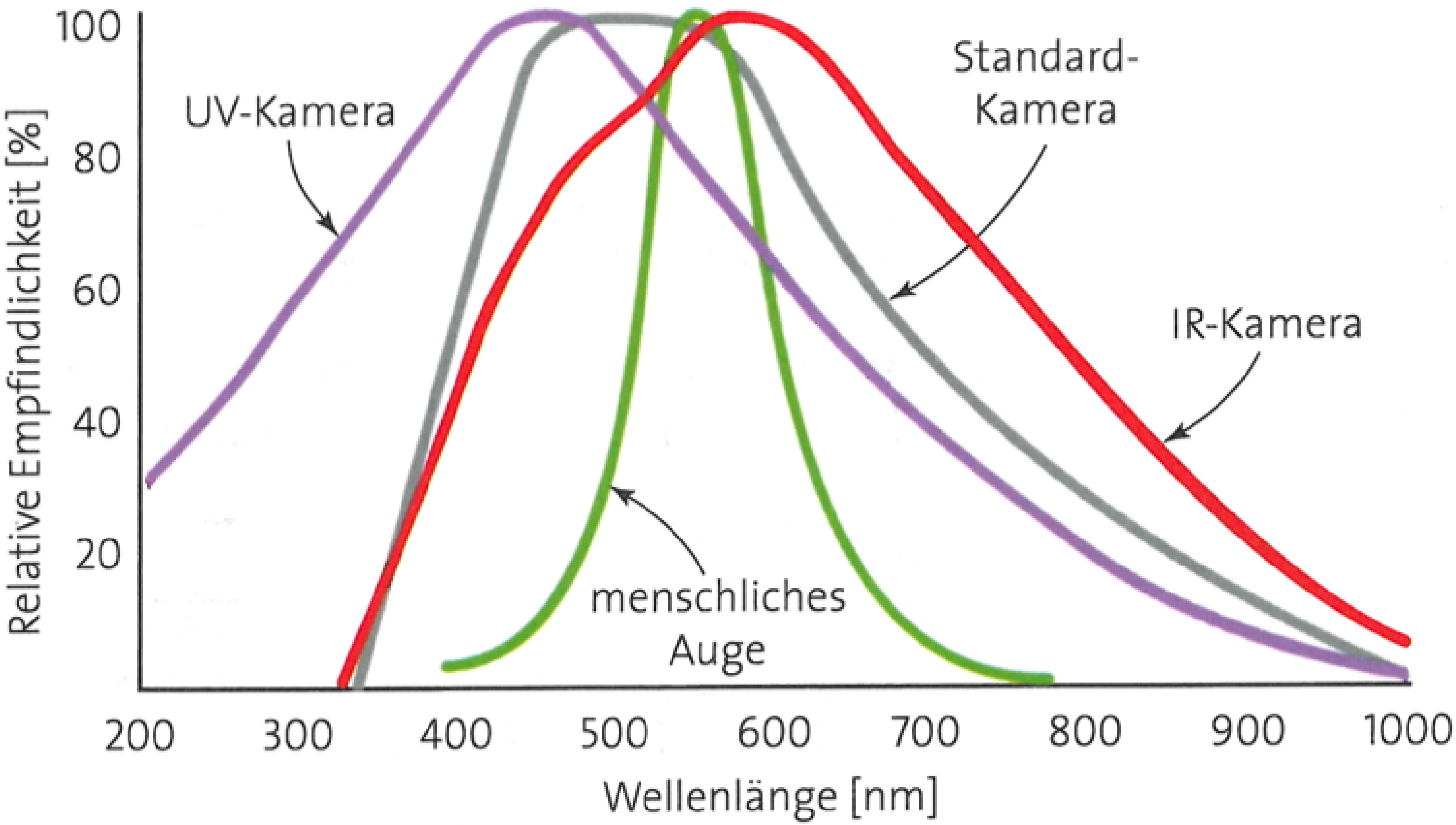
Digital Image Acquisition: Optics: Lens Mount

- Be aware of **different crop factors for fish eye** lenses:



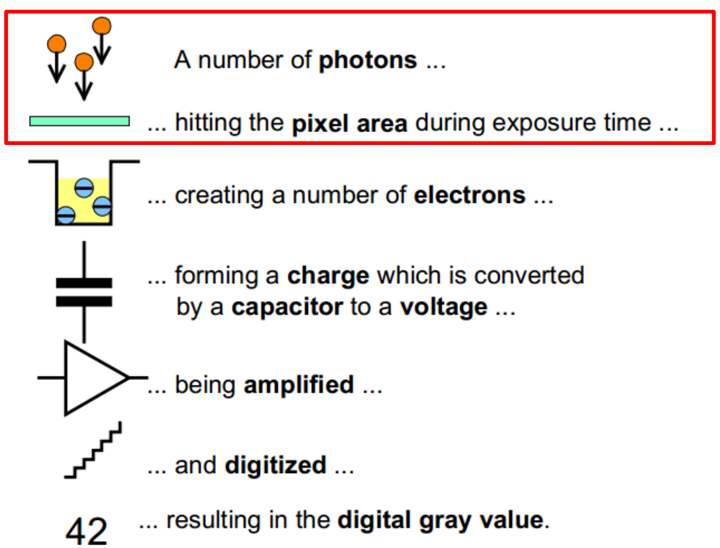
Digital Image Acquisition: Spectral Sensitivity

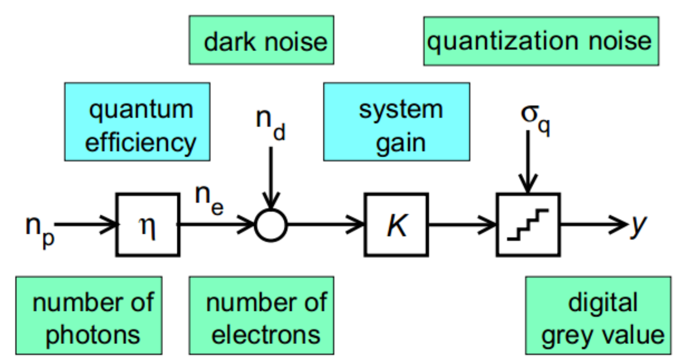
- The standard image sensor is more sensitive than the human eye.
- Extra UV- and IR-filters block out the unwanted spectras.
- Special spectra sensors have wider and shifted spectrum sensitivity.



Digital Image Acquisition: Sensors: Ideal Model

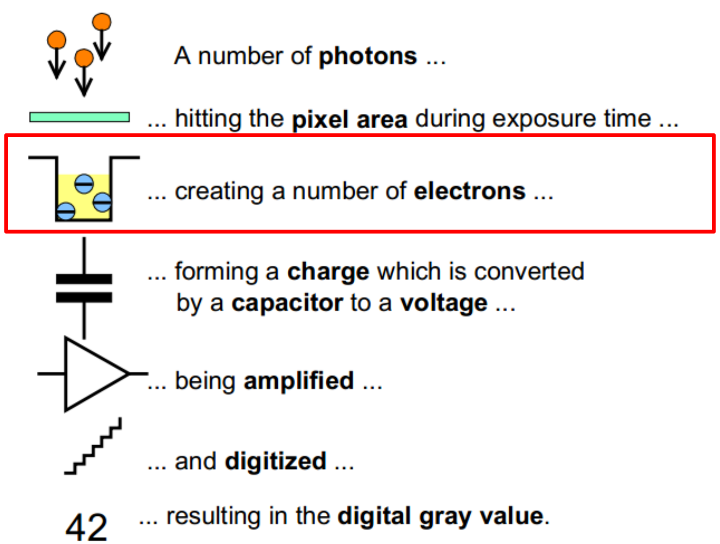
- The **EMVA-Standard 1288** (European Machine Vision Association) defines a model for Characterization of Image Sensors:
    - **Photons arrive on the sensor** (= light energy per time and area)

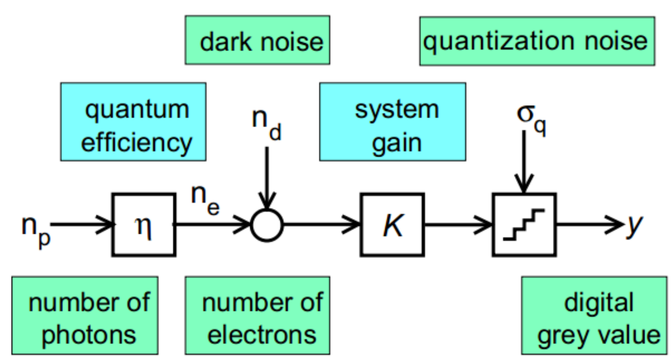




Digital Image Acquisition: Sensors: Ideal Model

- The **EMVA-Standard 1288** (European Machine Vision Association) defines a model for Characterization of Image Sensors:
  - Photons arrive on the sensor (= light energy per time and area)
  - The **quantum efficiency** is the probability that a photon produces an electron. It is about 50% on modern sensors.





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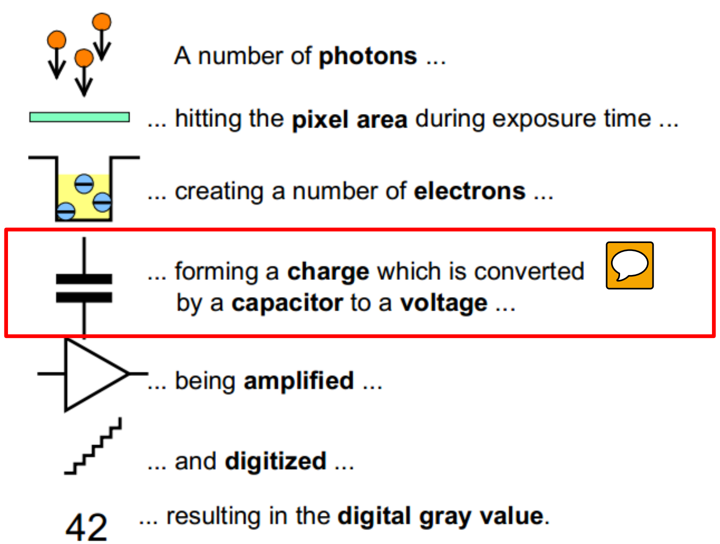
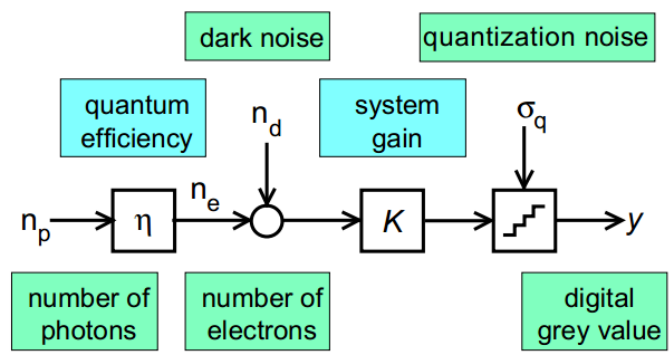
  - Photons arrive on the sensor (= light energy per time and area)
  - The quantum efficiency is the probability that a photon produces an electron.
  - **The number of electrons is proportional to the electric charge.**
    - **Full Well Capacity** is the max. possible charge.
    - More electrons > higher charge > **higher dynamic**.





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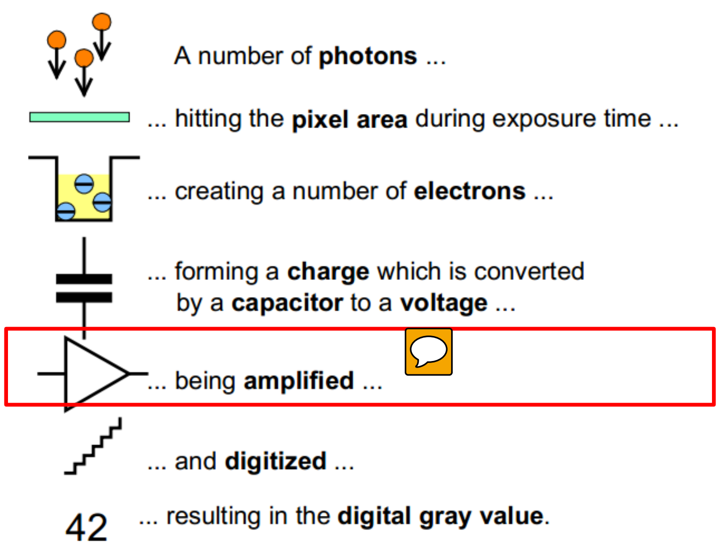
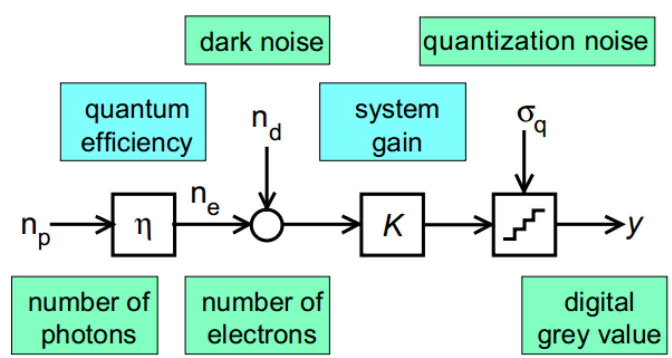
  - The number of electrons is proportional to the electric charge.
  - **The charge is small and must be amplified.**
    - **The more you ampify the more noise will be added.**





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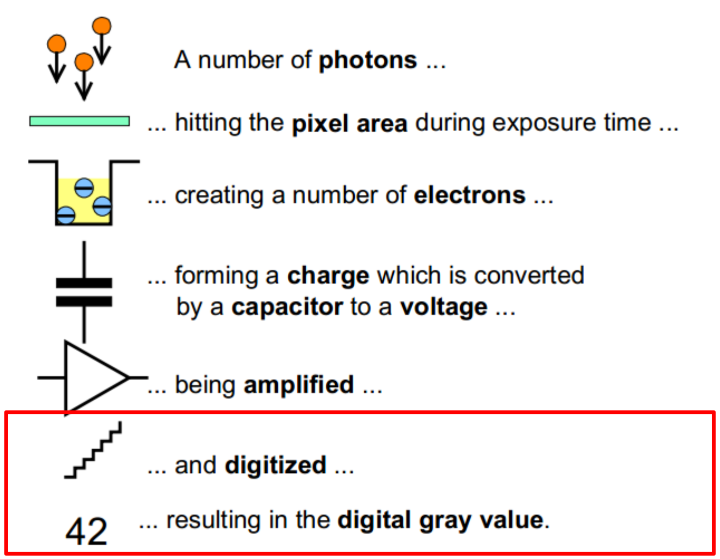
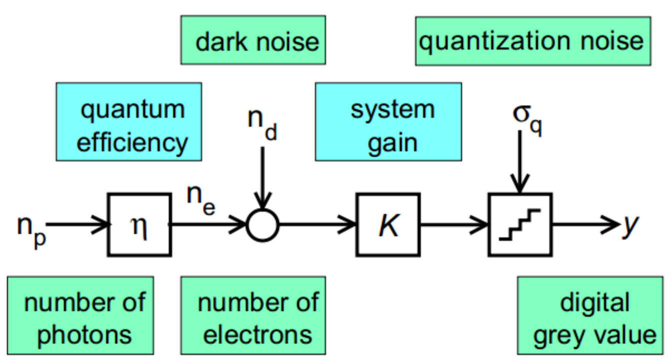
  - The charge is small and must be amplified.
  - **The amplified charge is converted by a analog to digital converter:**
    - Modern sensors have a 12-14 bit depth (4000-16'000 grayscales)





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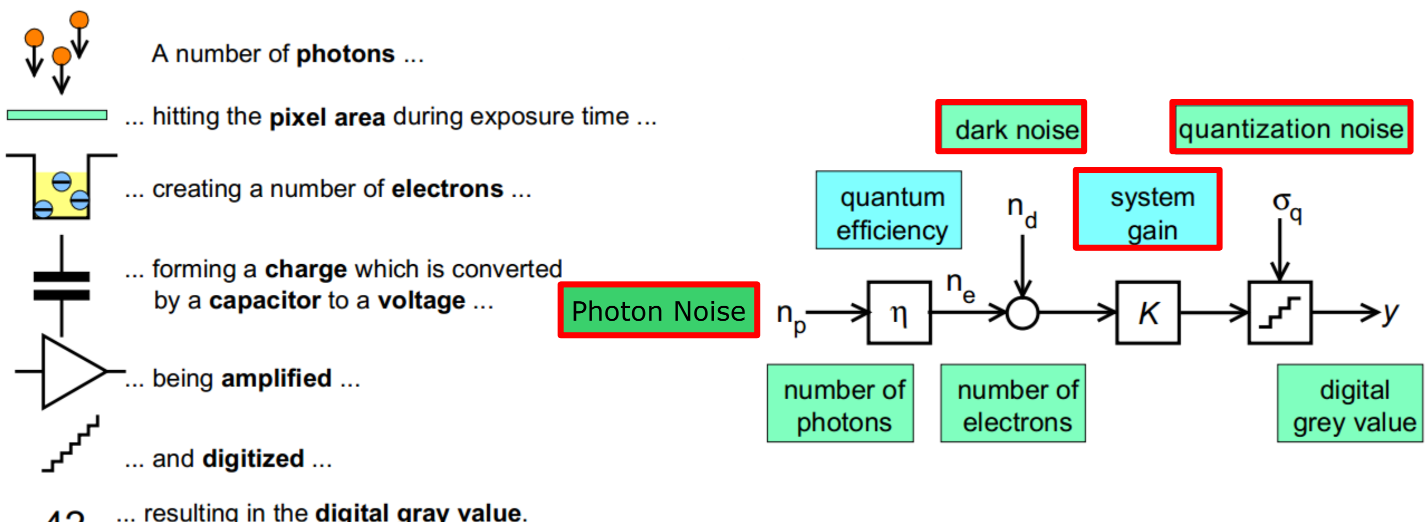
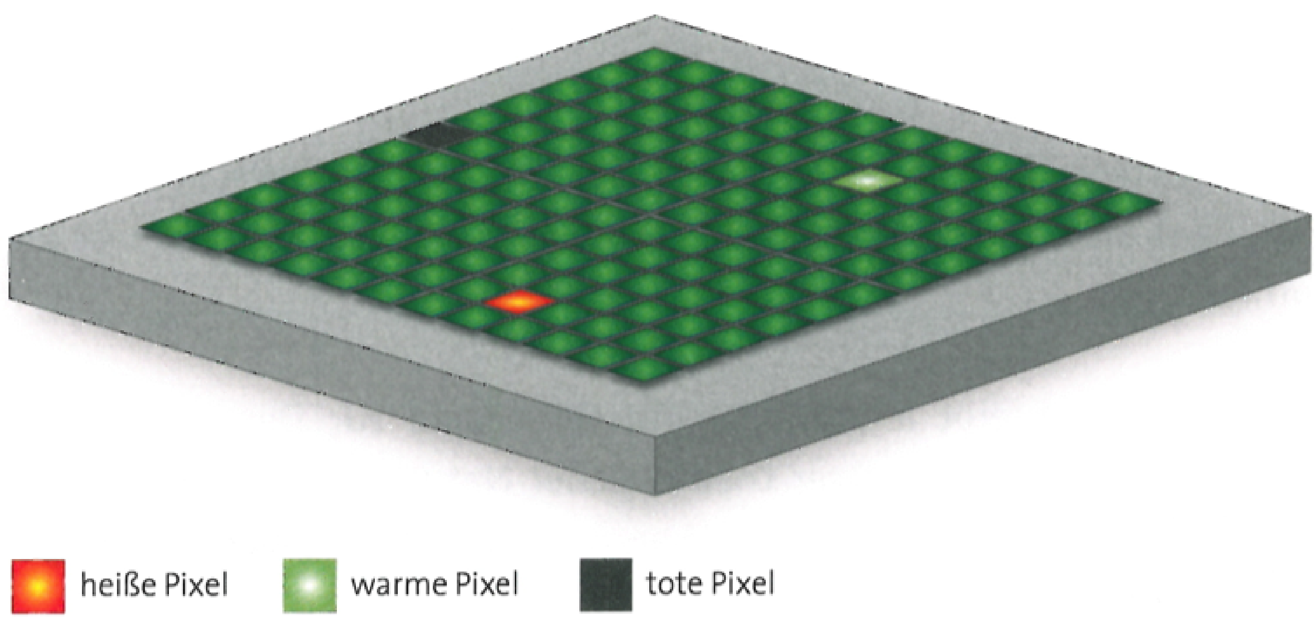
  - The number of electrons is proportional to the electric charge.
  - The charge is small and must be amplified.
  - The amplified charge is converted by a analog to digital converter.
  - **On all steps noise is added, but the most noise comes from the photon stream itself.**
    - The lower the noise and higher the dynamic, the better is the sensor



Digital Image Acquisition: Noise: Pixel Errors

- There are **many source for errors** in the image acquisition process.
- The production of an image sensor is a very complex process.
- **Not all pixels are perfect**:
  - **Hot pixels**: The charge is built without light.
  - **Warm pixels**: The charge does not correspond to the incomming light.
  - **Dead pixels**: No charge is built at all.

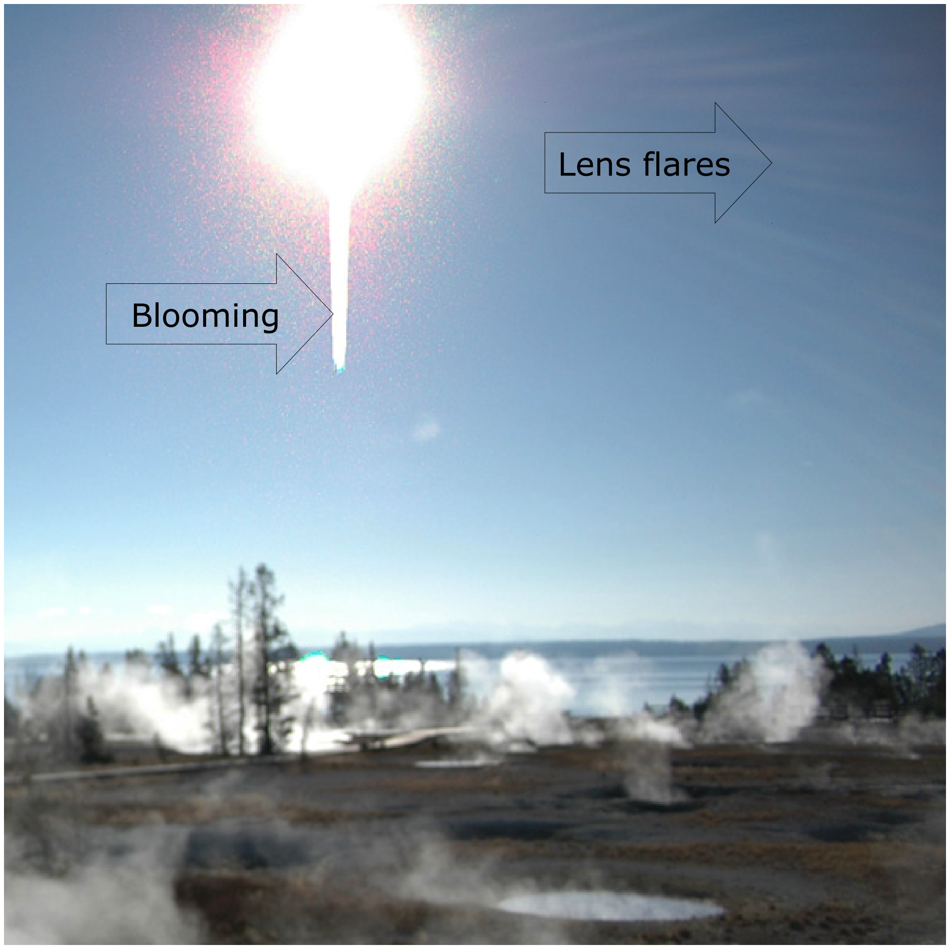


Digital Image Acquisition: Sensor Noise Types

- **Photon Noise (Photonenrauschen)**
  - Inherent in the photon stream.
  - Has natural poisson distribution.
  - It is the biggest portion of noise.
- **Dark Current Noise (Dunkelstrom)**
  - Produced in the sensor without light.
  - Mostly due to the temperature or pixel errors
  - Highquality sensors must be cooled.
- **Readout Noise (Ausleserauschen)**
- **Quantization Noise (Quantisierungsrauschen)**
- **Fixed Pattern Noise**
  - Not all pixels sum up the charge equally.
- **Gain Noise (Verstärkerrauschen)**

Digital Image Acquisition: Sensor: Blooming

- If the full well capacity is reached, older sensors tended to **flood over**.
- Modern sensors have **Anti-Blooming-Gate**.
- Blooming artefacts are not lens flares!



Digital Image Acquisition: Dark Frame Correction

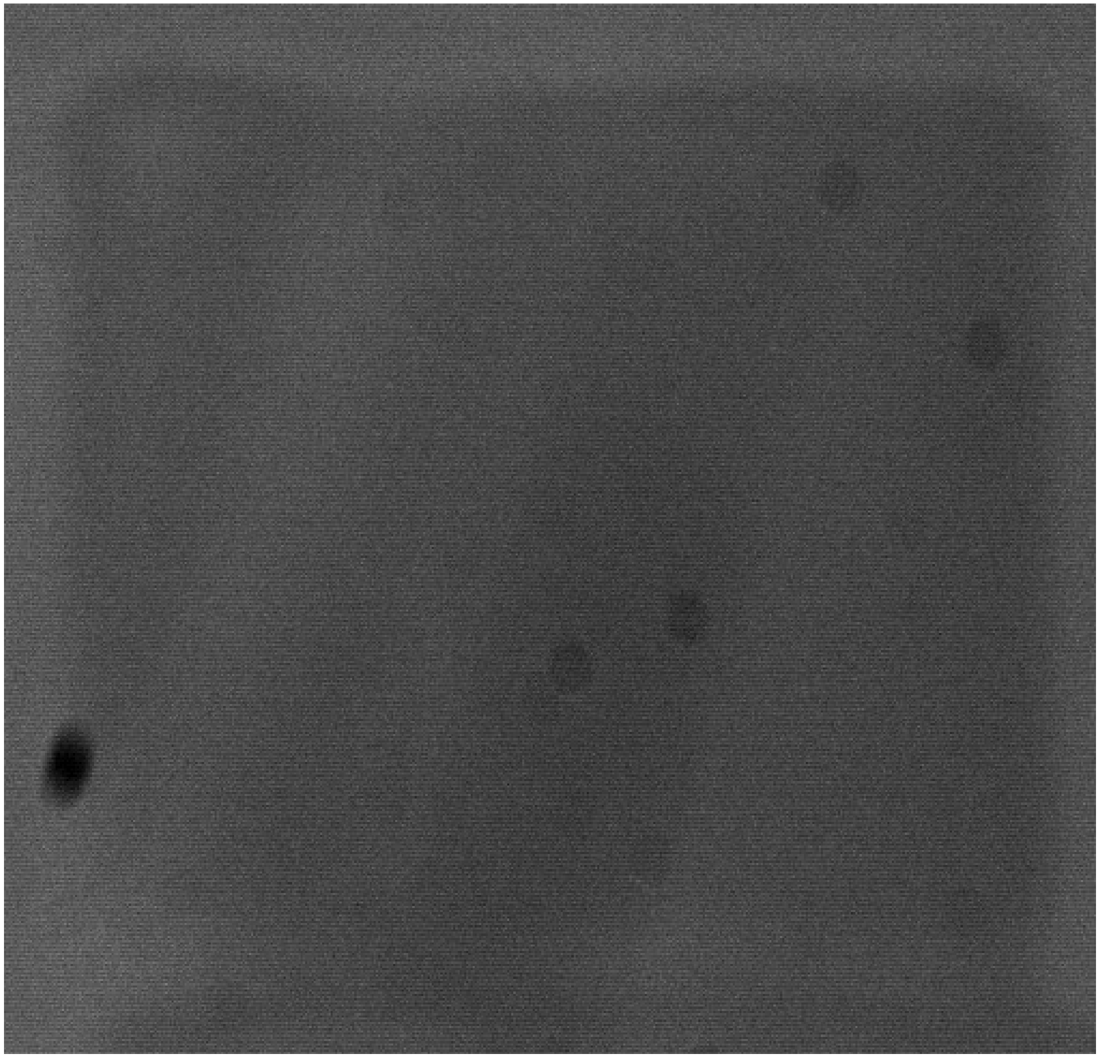
- For images with long exposure time we can subtract a dark frame image that was taken with the same exposure and temperature:

Digital Image Acquisition: Dark Frame Correction

- Dark frame image:

Digital Image Acquisition: Flat Field Correction

- Irregularities from fixed pattern noise or lens vignetting can be corrected by dividing a **flat field image** and multiplying it with the average of it.



A **flat field image** is also called **white frame** or **white image**.

It is created by with a equally illuminated white background.

Digital Image Acquisition: Flat Field Correction

- The star image after dark frame & flat field correction:

Digital Image Acquisition: Signal-to-Noise Ratio

- Signal-to-noise ratio (SNR) is ratio of a desired signal to the background noise.
- It is used in signal processing as a quality measure.

$$SNR = \frac{Signal}{Noise} = \frac{electrons_{signal}}{electrons_{noise}}$$

- For an ideal sensor with only the inherent photon noise (no dust, cooled & low gain) it is due to the poisson distribution:

$$SNR = \sqrt{N_{electrons}}$$

Photons	SNR	Noise
9	3	33%
100	10	10%
900	30	3%
10000	100	1%
90000	300	0.3%

low light > high noise

Digital Image Acquisition: Signal-to-Noise Ratio

- Because the noise is mostly only a fraction of the signal power, the SNR is set into a logarithmic scale with the pseudo unit [dB]:

$$SNR = 20 \cdot \log\left(\frac{Signal}{Noise}\right) \quad [\mathrm{dB}]$$

Digital Image Acquisition: Signal-to-Noise Ratio

- If we have 2 image A & B:
  - A is an image without noise
  - B is A with noise
- We can calculate the noise as the **Root Mean Squared Error** (**RMSE**):

$$RMSE = \sqrt{MSE} = \sqrt{\frac{1}{mn} \sum_{x=1}^{m} \sum_{y=1}^{n} \left(A(x, y) - B(x, y) \right)^2}$$

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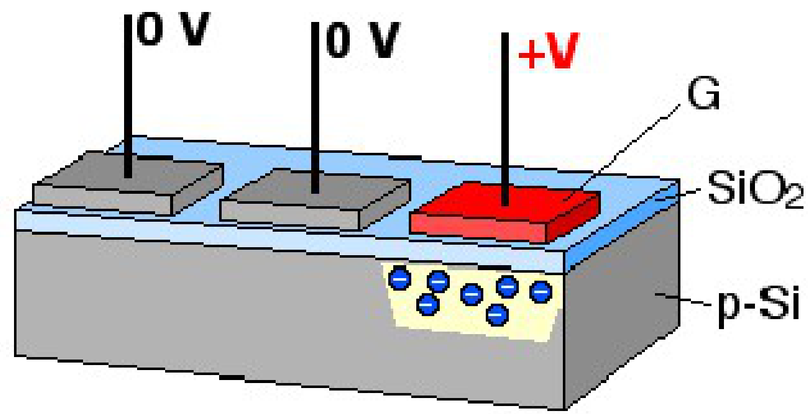
- The PSNR measure is then:

$$PSNR = 10 \cdot \log_{10} \left(\frac{255^2}{MSE} \right) = 20 \cdot \log_{10} \left(\frac{255}{RMSE} \right) \quad [dB]$$

100.000% Error >	PSNR = 20*log(255/	255.00000) =	0 dB
10.000% Error >	PSNR = 20*log(255/	25.50000) =	20 dB
1.000% Error >	PSNR = 20*log(255/	2.55000) =	40 dB
0.100% Error >	PSNR = 20*log(255/	0.25500) =	60 dB
0.010% Error >	PSNR = 20*log(255/	0.02550) =	80 dB
0.001% Error >	PSNR = 20*log(255/	0.00255) =	100 dB

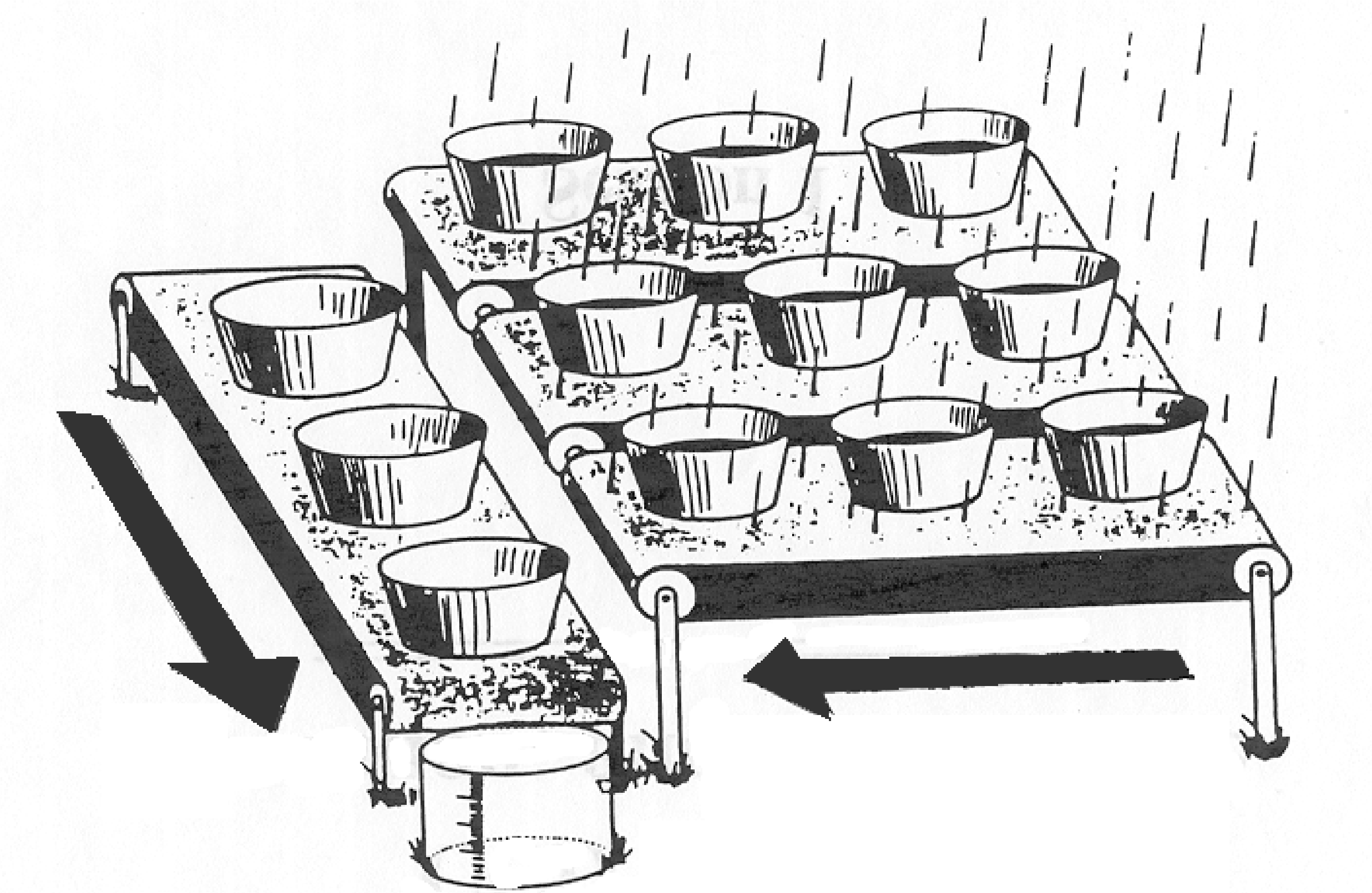
Digital Image Acquisition: Sensors Type: CCD

- **CCD** stands for **Charge Coupled Devices** (ladungsgekoppelte Verschiebeeinheit)
- The photonen produce electric charge
- The charge is proportional to the incomming amount of light x quantum efficiency.
- The charge is serially shifted:

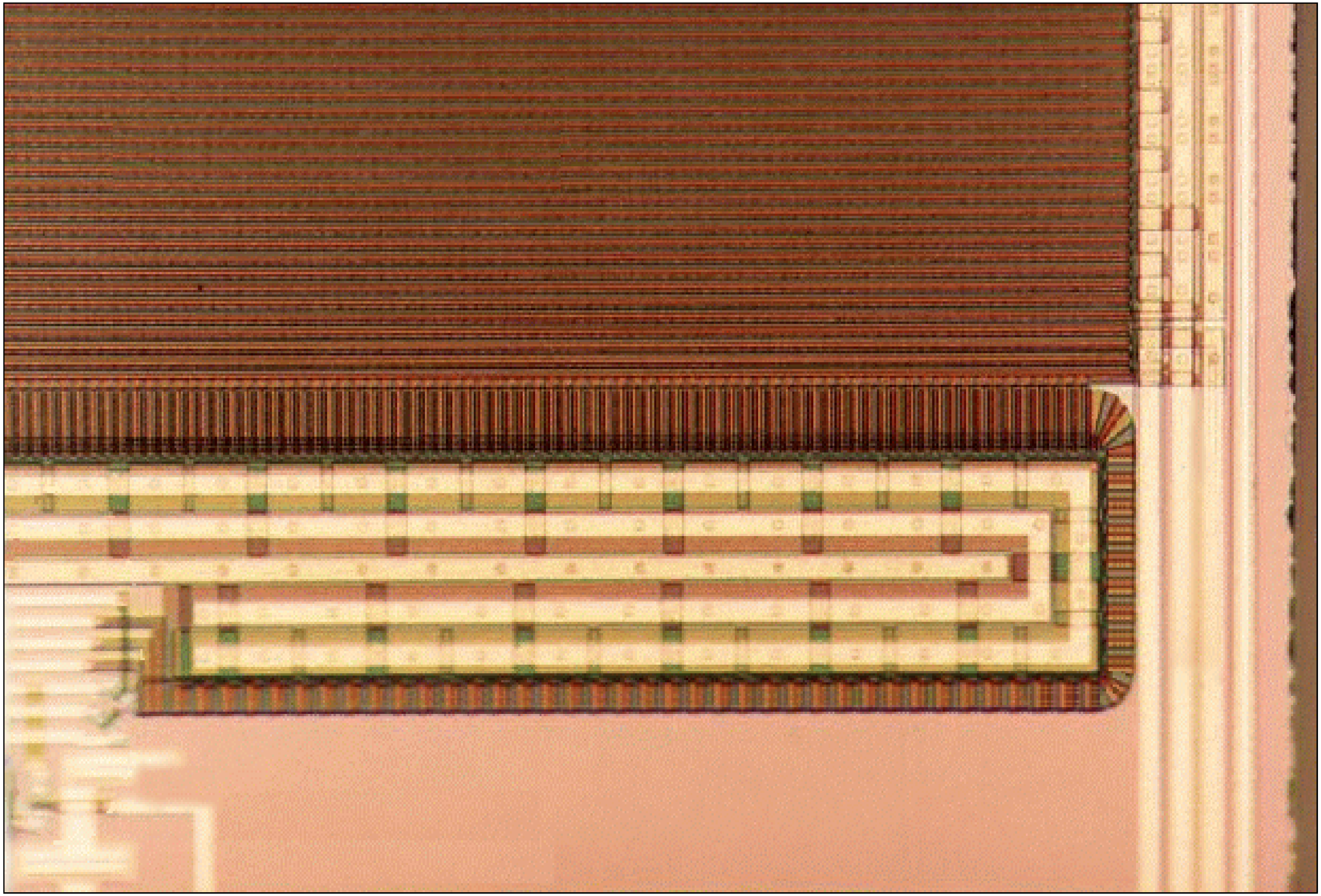


Digital Image Acquisition: Sensors Type: CCD

- Sensor cells are also called wells (Engl. für Brunnen oder Potentialtöpfe)



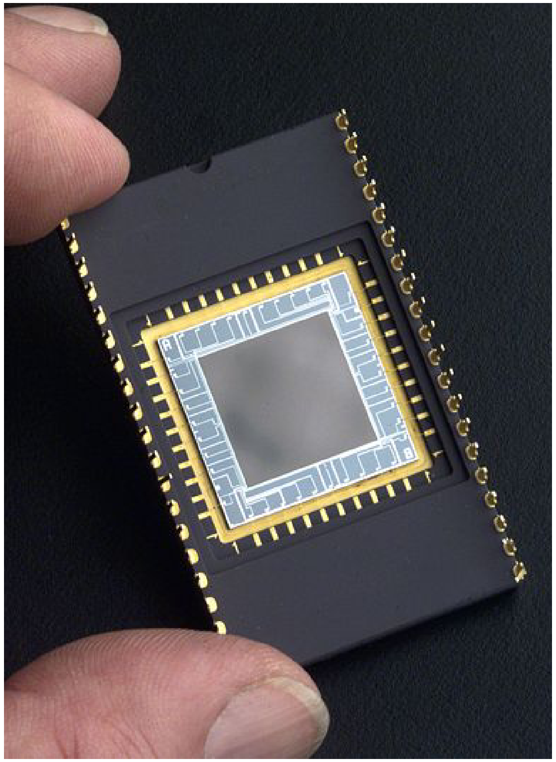
Digital Image Acquisition: Sensors Type: CCD

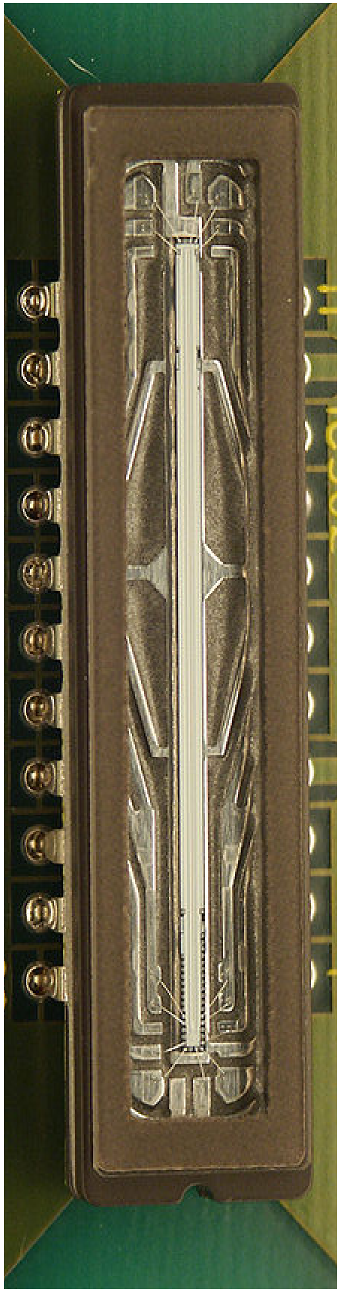


Digital Image Acquisition: Sensors Type: CCD

- **G. Smith** & **W. Boyle** invented the CCD at **AT&T in 1959**
- They where honoured with the **Nobel prize in 2009**

Digital Image Acquisition: Sensors Type: CCD

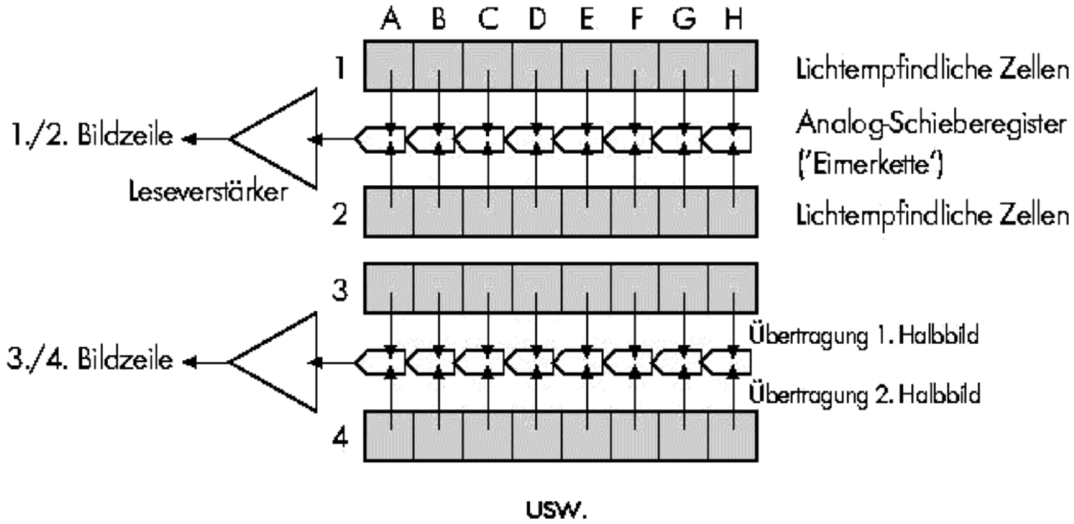




Digital Image Acquisition: Sensors Type: CCD

Interlaced CCD

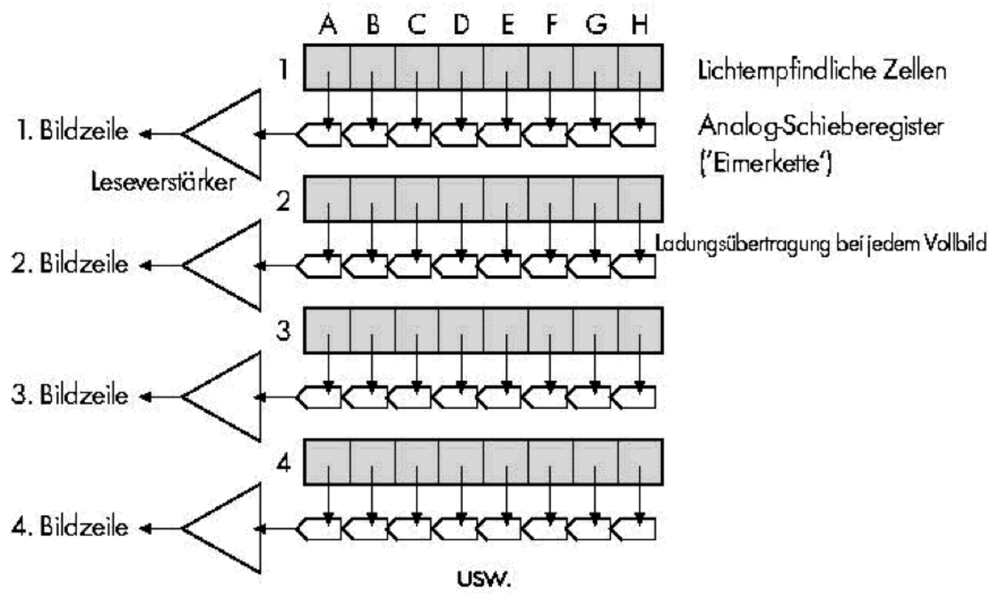
- Captures odd & even lines separately in two images
- Can lead edgy artefacts
- Come from the analog TV standards PAL & NTSC
- 25 half frames x 2 = 50 Hz



Digital Image Acquisition: Image Sensors: CCD

Progressive Scan CCD

- Each line has its shifting registers
- Captures full frames
- Doubled data rate compared to interlaced CCD



Digital Image Acquisition: Sensors Type: CCD

Advantages of CCD Sensors:

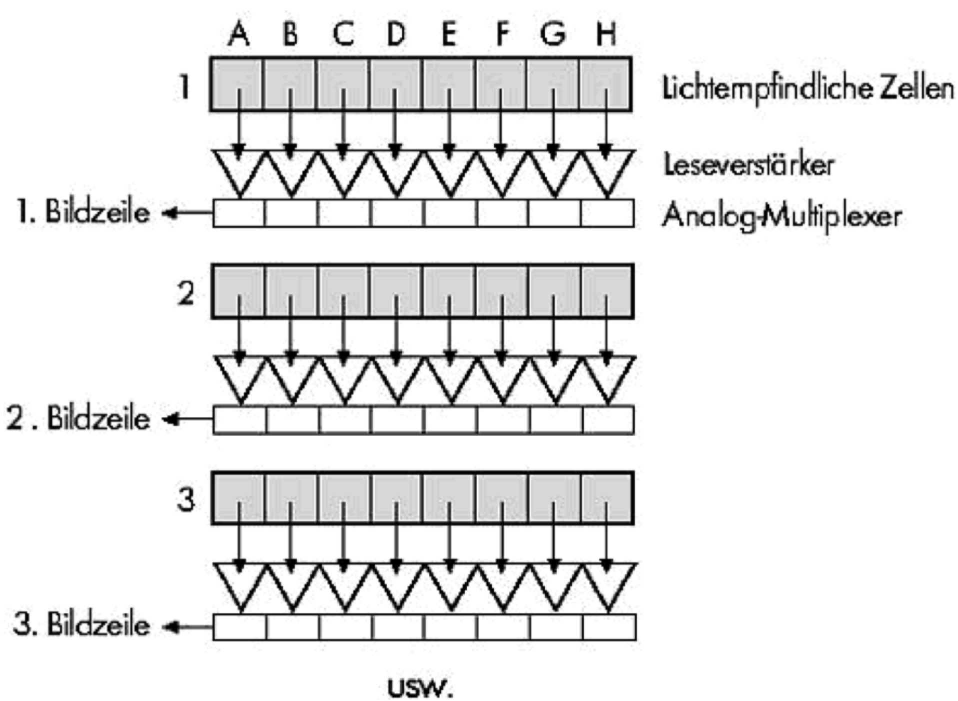
- Sensitive part per cell is high > high dynamic > high sensitivity
- There is no other electronic on the sensor > lower noise

Disadvantages of CCD Sensors:

- Higher power consumption
- Only full frames or half frames, no ROIs (region of interest).
- Slower due to serial output (only true for Full Frame CCDs)
    - See Wikipedia for different CCD type.

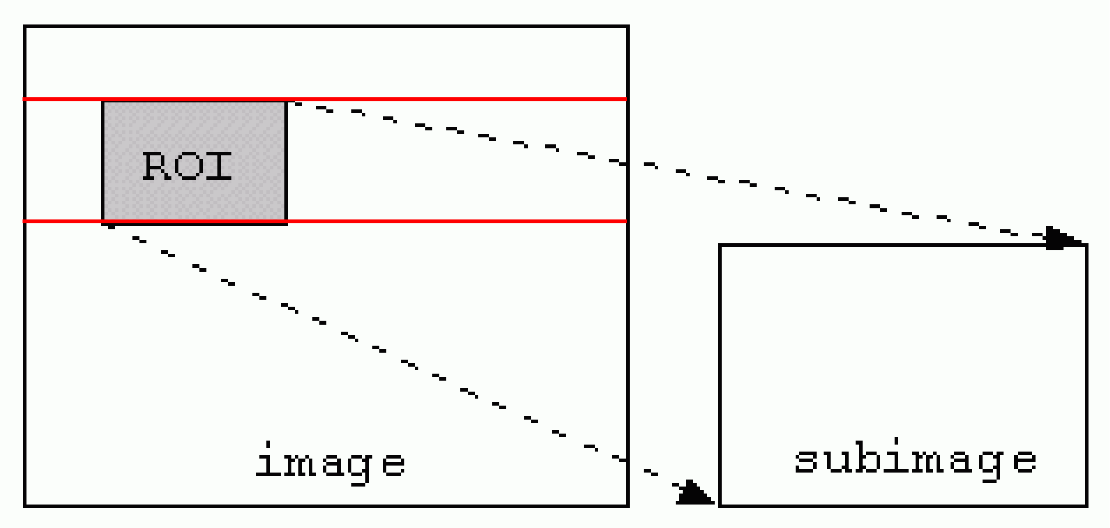
Digital Image Acquisition: Sensors Type: CMOS

- **CMOS** stands for **Complementary Metal Oxide Semiconductor**
- Every photo cell has its **own amplifier**
- All cells are **read out in parallel**
- Cells can be addressed directly over **x- & y-coordinates**
- Sensor can contain entire camera processing



Digital Image Acquisition: Sensors Type: CMOS

- Region of Interest (ROI) can be defined.
- ROIs can be read out proportionally faster:



Digital Image Acquisition: Sensors Type: CMOS

- CMOS sensors can have a **global** or **rolling shutter**.
- **With rolling shutter**
  - Production is **cheaper** (one transistor per pixel less).
  - Shutter time of single line can be extremely **fast** > Motions get distorted
  - **No flash** illumination is possible.

Digital Image Acquisition: Sensors Type: CMOS

Advantages of CMOS Sensors:

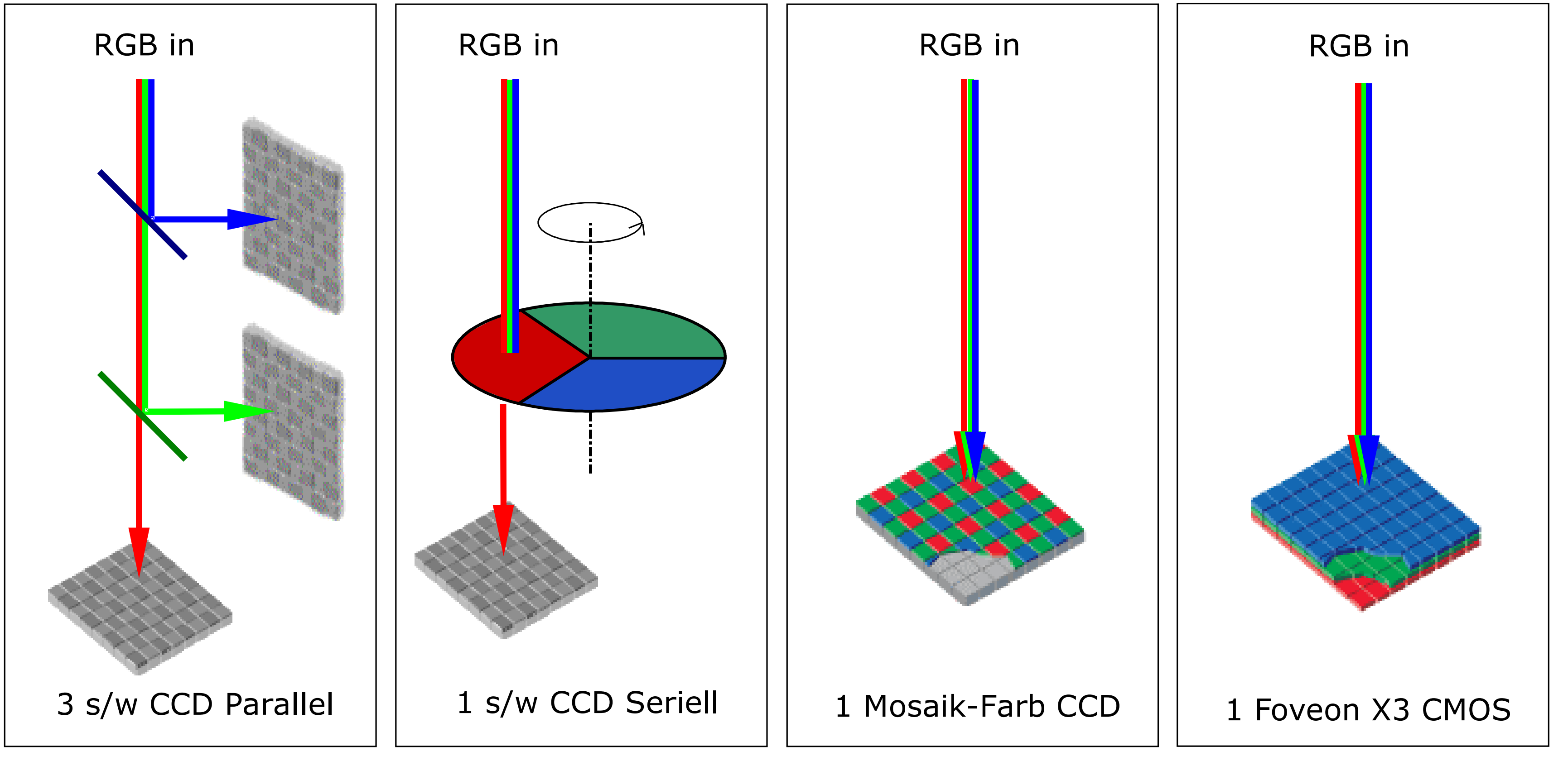
- In general **faster** due parallel read out.
- Region of Interest (**ROI**).
- **Higher resolution** due to standard waver production
- **Higher integration**
  - **lower production cost**
  - **All in one camera solutions**

Disadvantages of CMOS Sensors:

- **Lower sensibility** due lower fill rate
- **More noise** due amplification per pixel
  - This is reduced today with expensive denoising filtering on chip.

Digital Image Acquisition: Color Acquisition

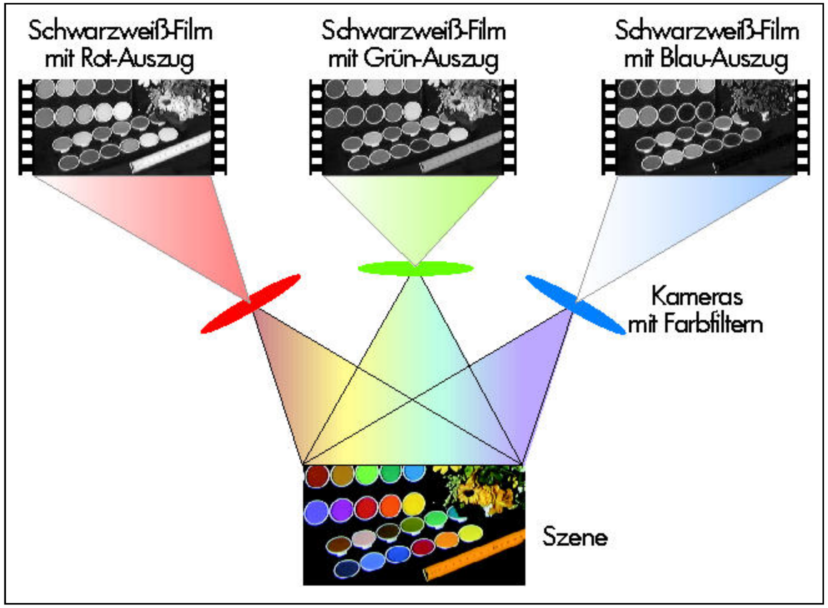
- Color image with 3 B/W sensors parallel
- Color image with 1 B/W sensor seriell
- Color image with 1 sensor and Bayer filter pattern
- Color image with 1 color sensor (Foveon)



Digital Image Acquisition: Color Acquisition in RGB

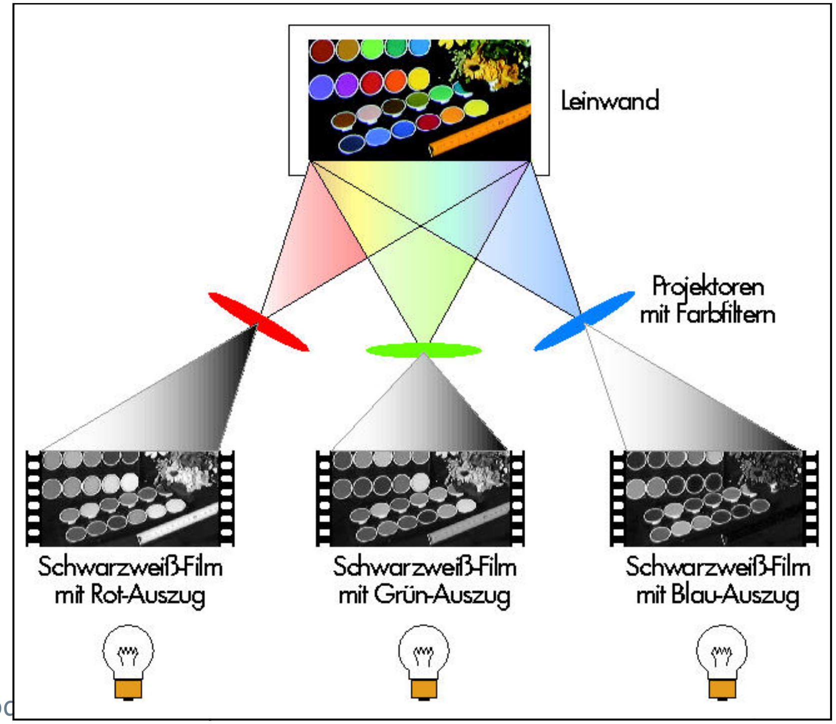
Acqiusition

- 3 separate, red, green & blue filtered B/W images.



Projektion

- 3 separate, red, green & blue filtered B/W-images reprojeted produce the color image.

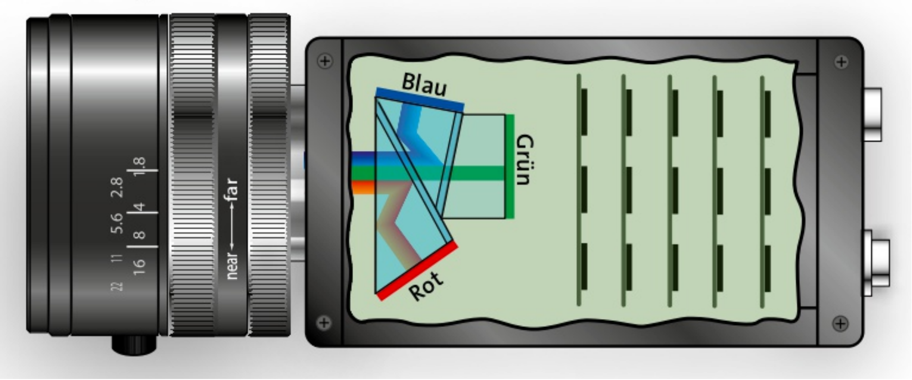


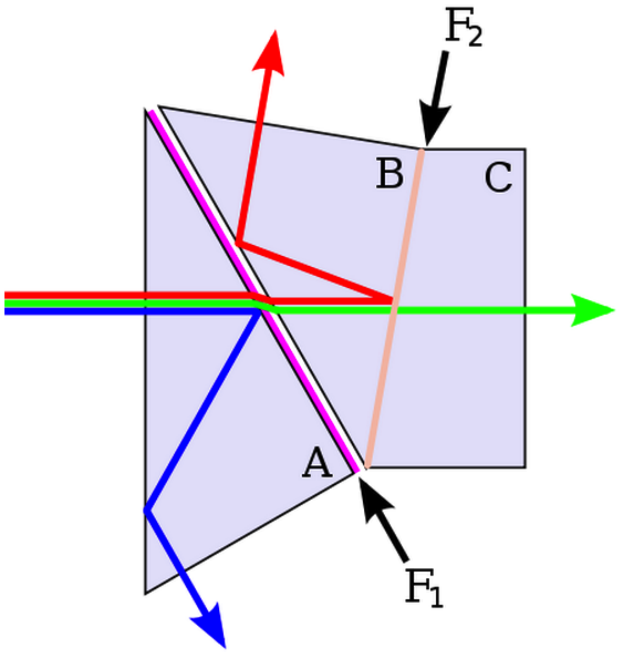
Digital Image Acquisition: Color Acquisition: RGB

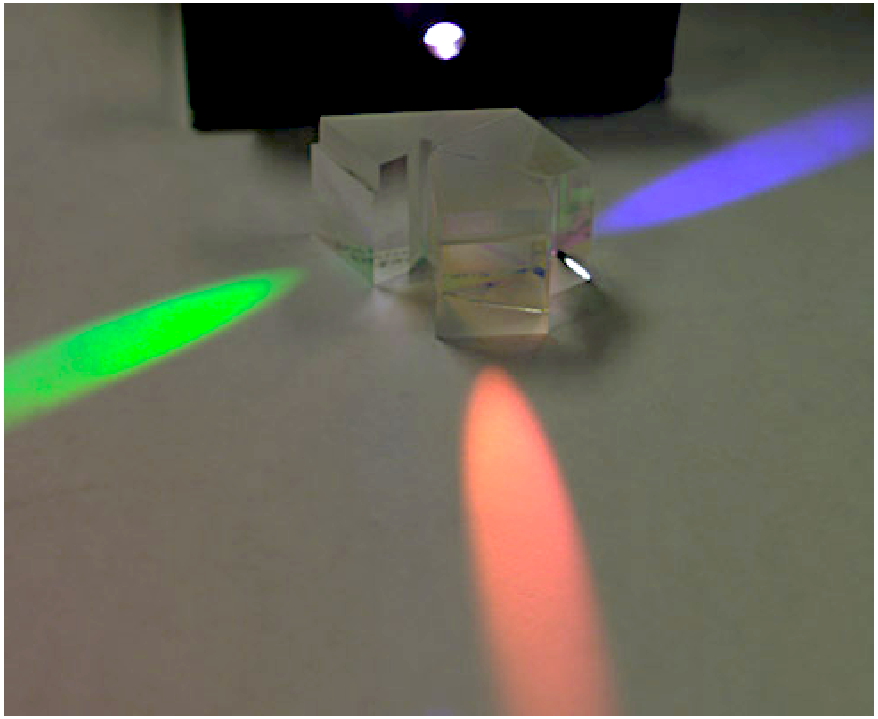
- The principle is old: Color image assembled from 3 B/W images 1911:

Digital Image Acquisition: 3-CCD-Color Acquisition

- 3-Sensor cameras can capture all channels parallel.
- A filter prisma splits the RGB colors.
- Mostly found in video cameras

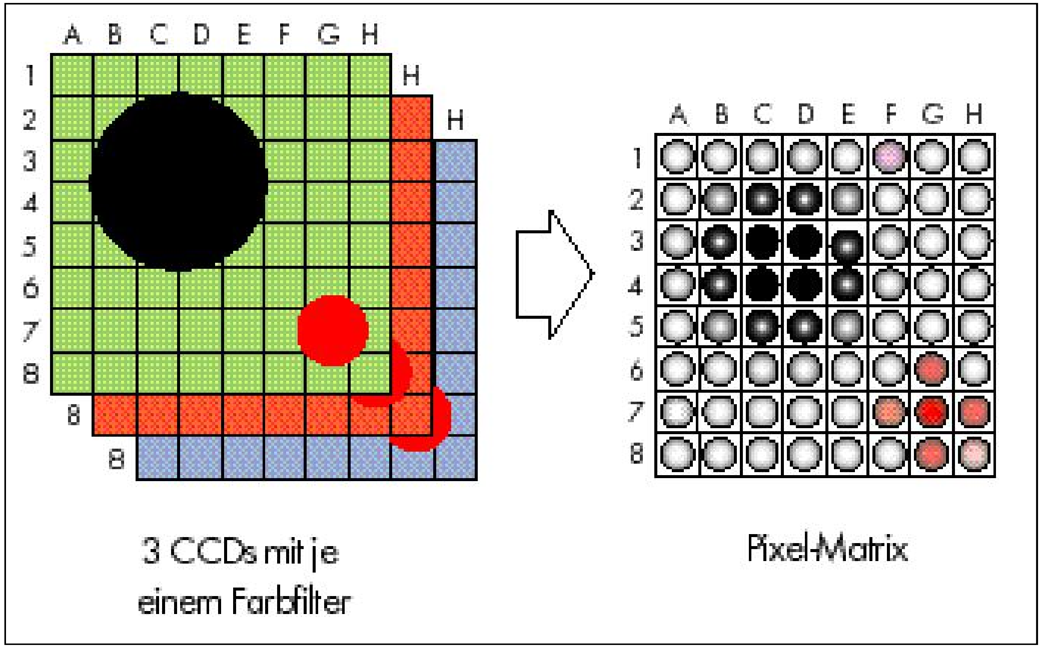






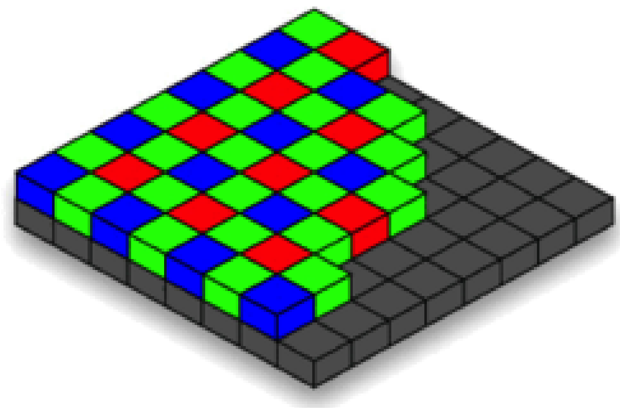
Digital Image Acquisition: Full Color Acquisition

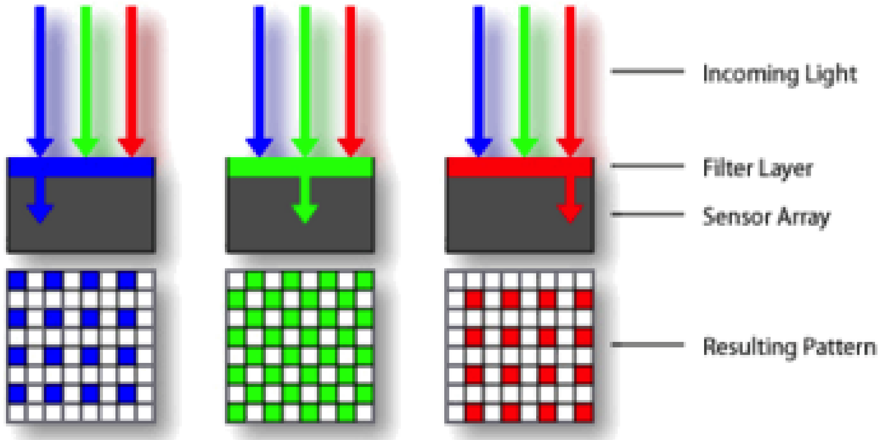
- 3-Sensor cameras can capture all channels parallel.
- Each sensor has it color filter.
- 1-Sensor cameras with a color wheel can capture the full color information serial.



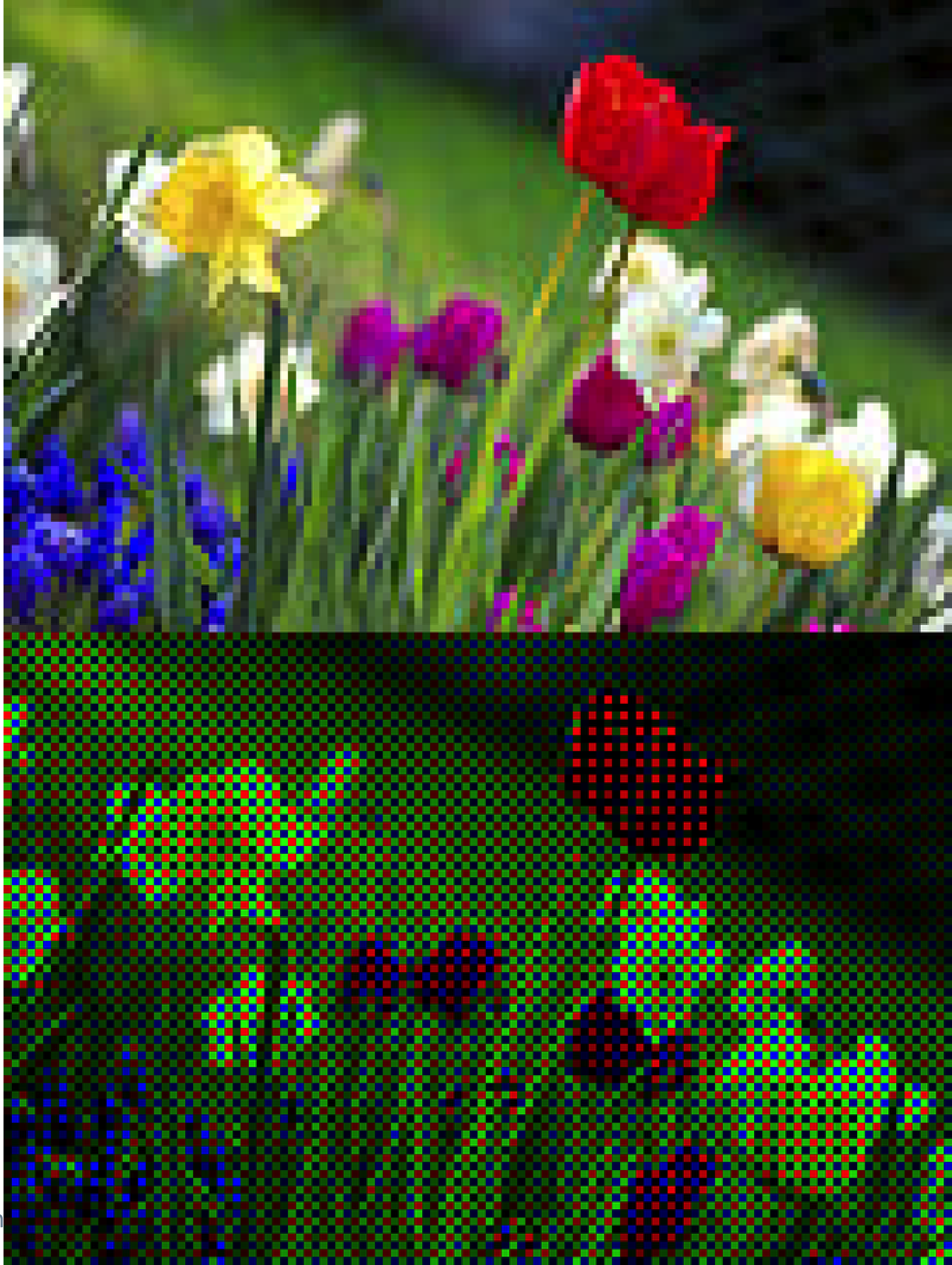
Digital Image Acquisition: Bayer Pattern

- The standard **„Color Sensor"** uses a color filter pattern called **Bayer pattern**.
- On single pixel we therefor have **only one color** information.
- Due to higher human green sensitivity the green filters appear doubled.



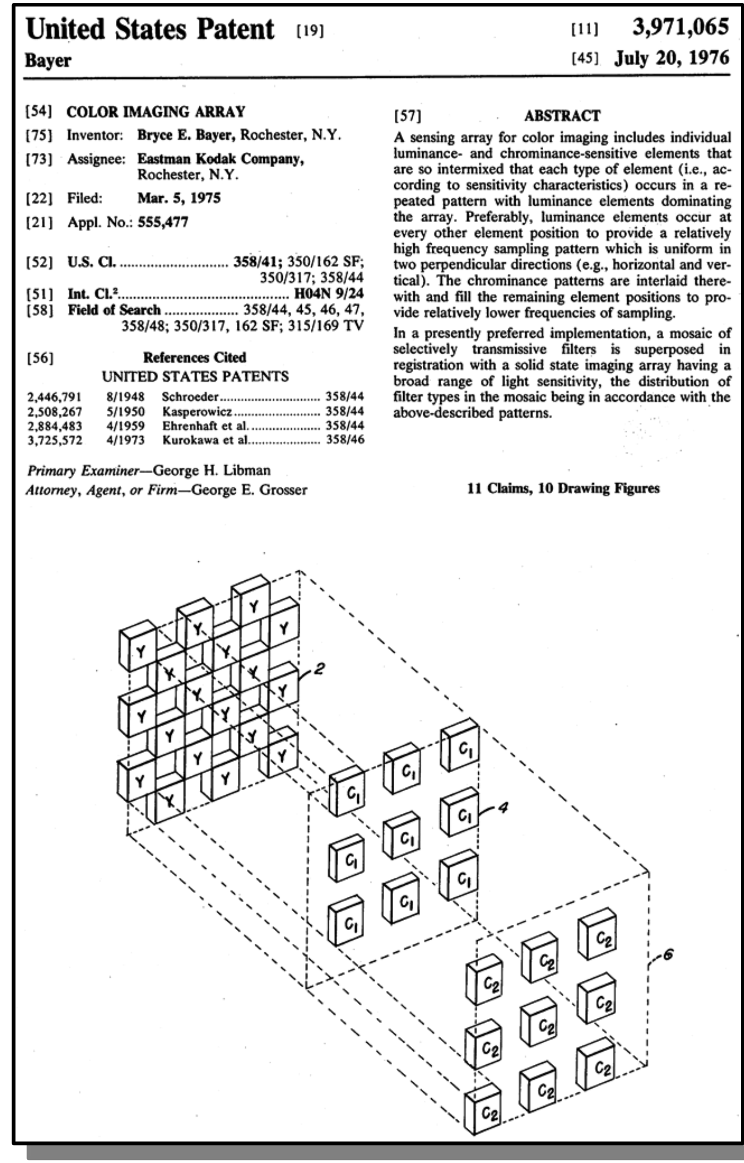


Digital Image Acquisition: Bayer Pattern Filter



Digital Image Acquisition: Bayer Pattern

- Bryce Bayer invented this pattern at Eastman Kodak.
- It is one of hundreds of patents that Kodak achieved and had to sell now to Apple & Google



United States Patent [19] — **Bayer**

[11] **3,971,065**
[45] **July 20, 1976**

[54] **COLOR IMAGING ARRAY**
[75] Inventor: **Bryce E. Bayer,** Rochester, N.Y.
[73] Assignee: **Eastman Kodak Company,** Rochester, N.Y.
[22] Filed: **Mar. 5, 1975**
[21] Appl. No.: **555,477**

[52] **U.S. Cl.** .... **358/41;** 350/162 SF; 350/317; 358/44
[51] **Int. Cl.²** **H04N 9/24**
[58] **Field of Search** .... 358/44, 45, 46, 47, 358/48; 350/317, 162 SF; 315/169 TV

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Primary Examiner—George H. Libman
Attorney, Agent, or Firm—George E. Grosser

[57] **ABSTRACT**

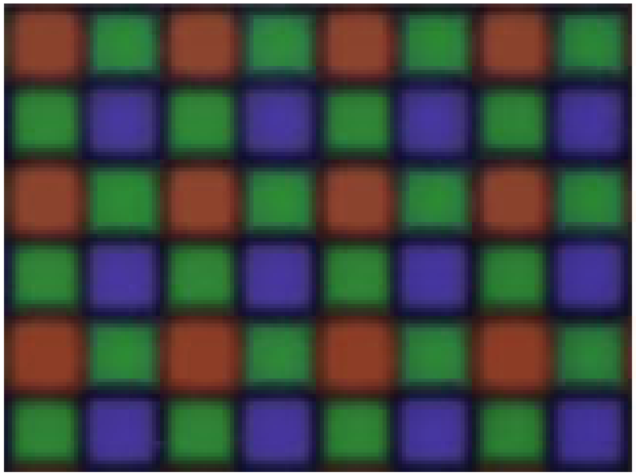
A sensing array for color imaging includes individual luminance- and chrominance-sensitive elements that are so intermixed that each type of element (i.e., according to sensitivity characteristics) occurs in a repeated pattern with luminance elements dominating the array. Preferably, luminance elements occur at every other element position to provide a relatively high frequency sampling pattern which is uniform in two perpendicular directions (e.g., horizontal and vertical). The chrominance patterns are interlaid therewith and fill the remaining element positions to provide relatively lower frequencies of sampling.

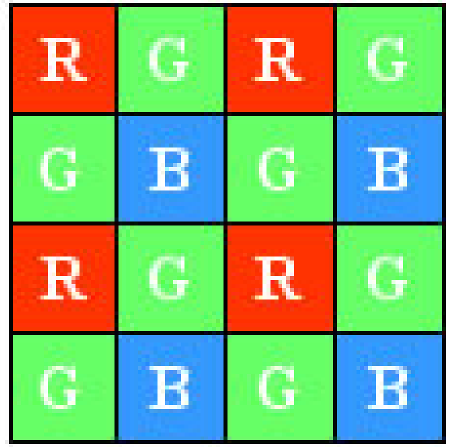
In a presently preferred implementation, a mosaic of selectively transmissive filters is superposed in registration with a solid state imaging array having a broad range of light sensitivity, the distribution of filter types in the mosaic being in accordance with the above-described patterns.

11 Claims, 10 Drawing Figures

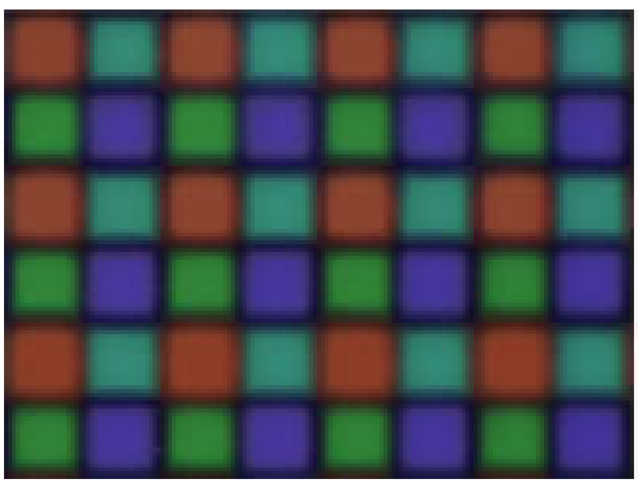
Digital Image Acquisition: Bayer Pattern

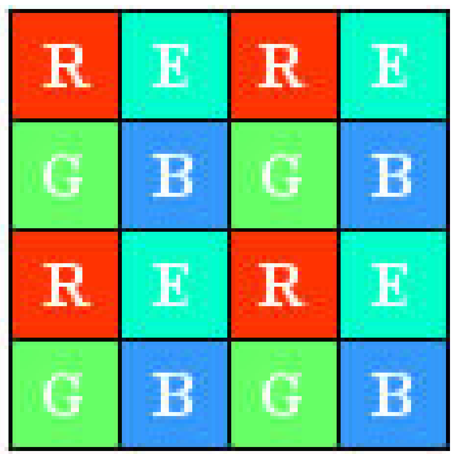
- There are alternative patterns and colors:





RGB

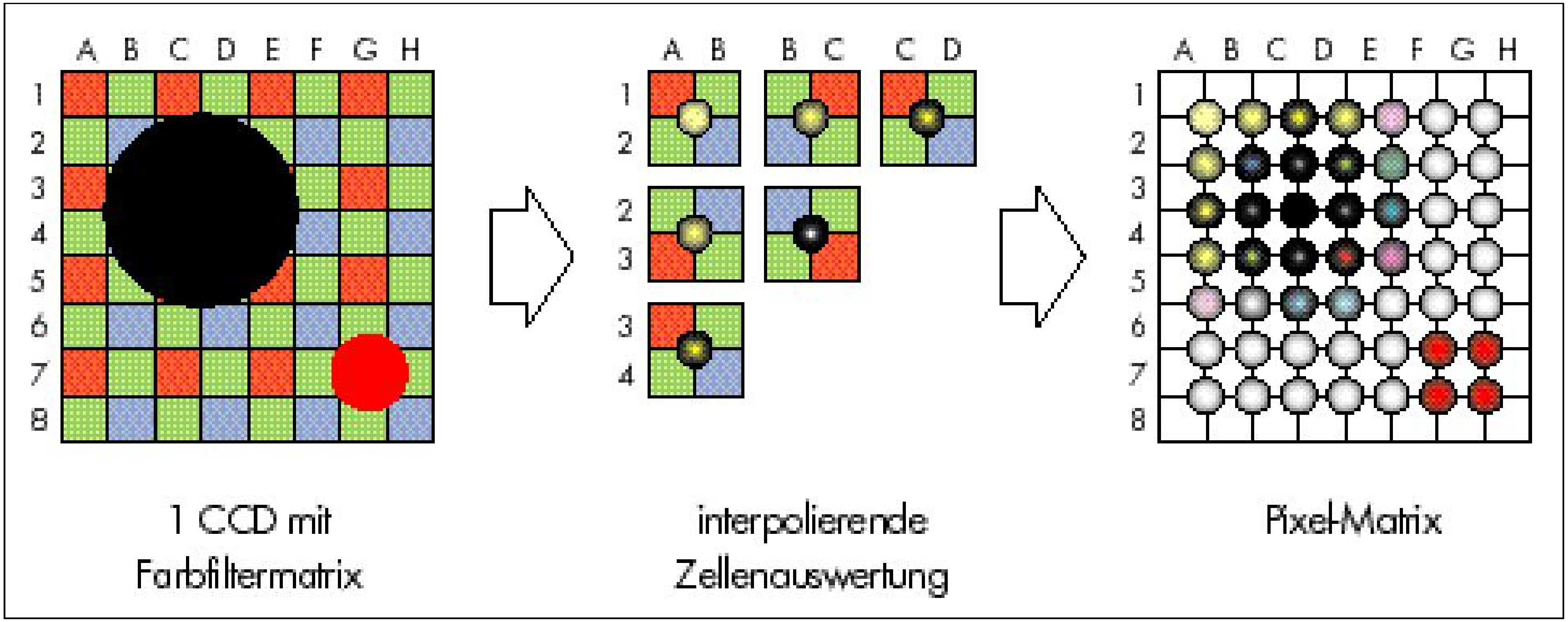




RGBE (E wie Emerald)

Digital Image Acquisition: Debayering

- For a full color image we must interpolate the missing information.
- Simplest interpolation is to half the resolution and average the colors of 4 pixels
- At edges of strong contrast we get noticable interpolation errors (color noise):

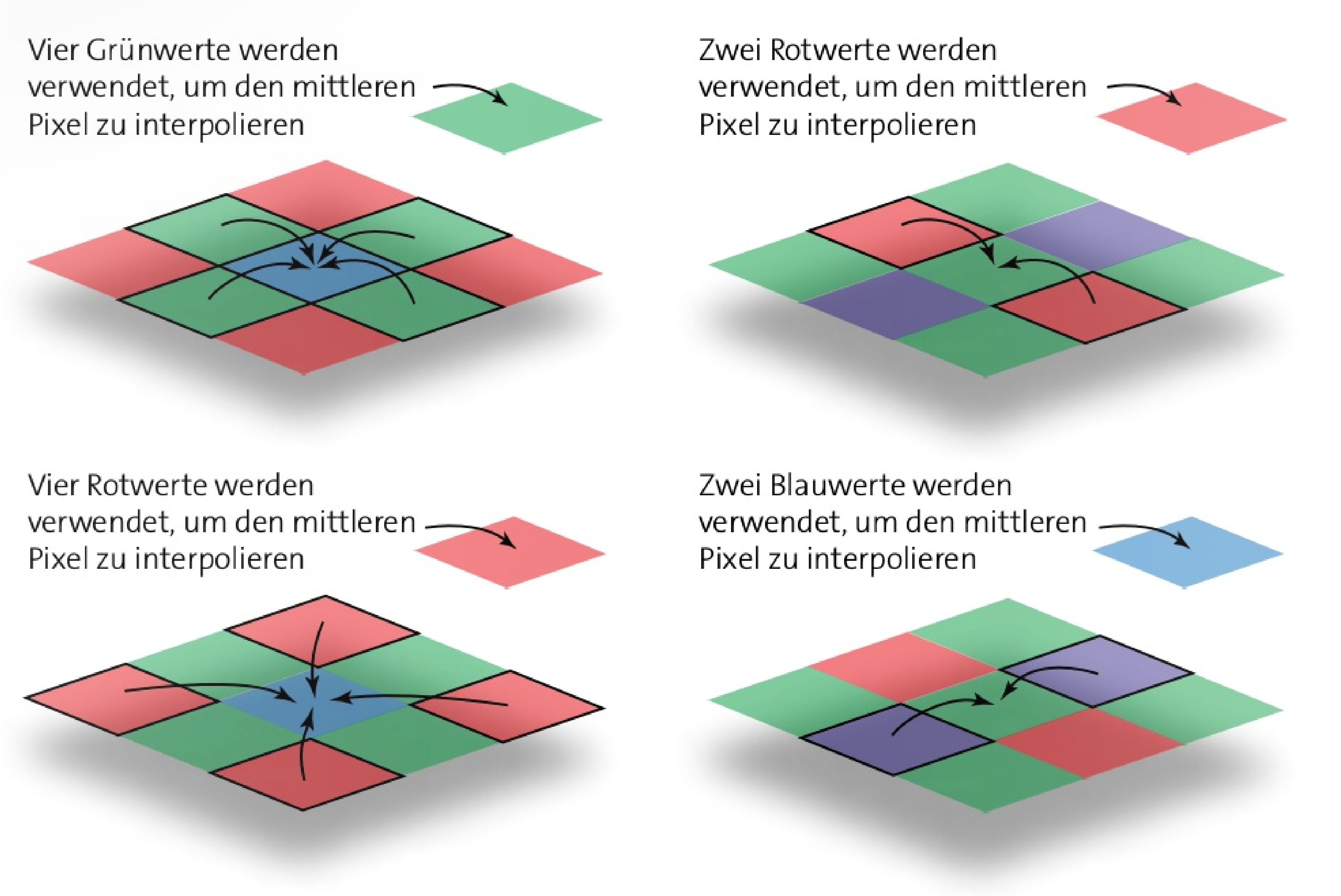


Digital Image Acquisition: Debayering

- For a full color image we must interpolate the missing information.
- Simplest interpolation is to half the resolution and average the colors of 4 pixels
- At edges of strong contrast we get noticable interpolation errors (color noise):

Digital Image Acquisition: Debayering

- The simplest full resolution debayering interpolation is to average the missing colors from the surrounding colors:

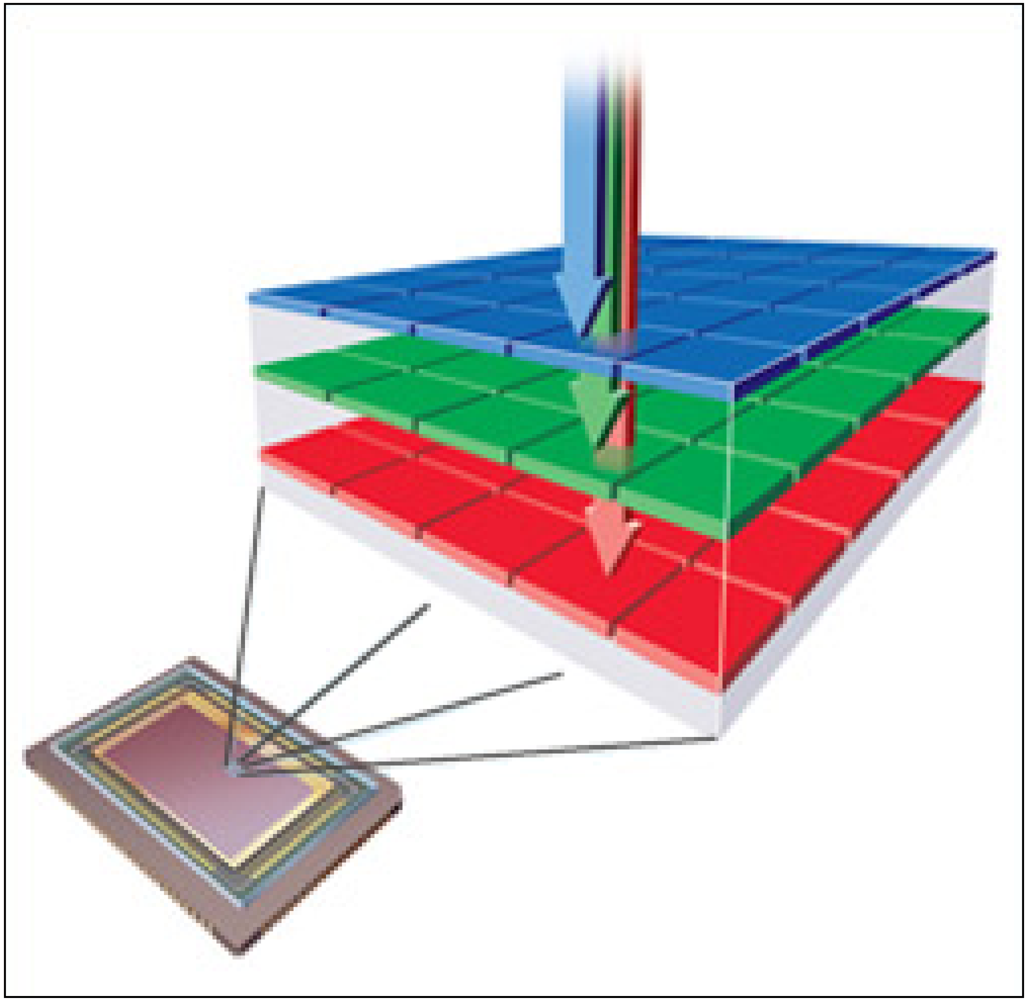


Digital Image Acquisition: Debayering

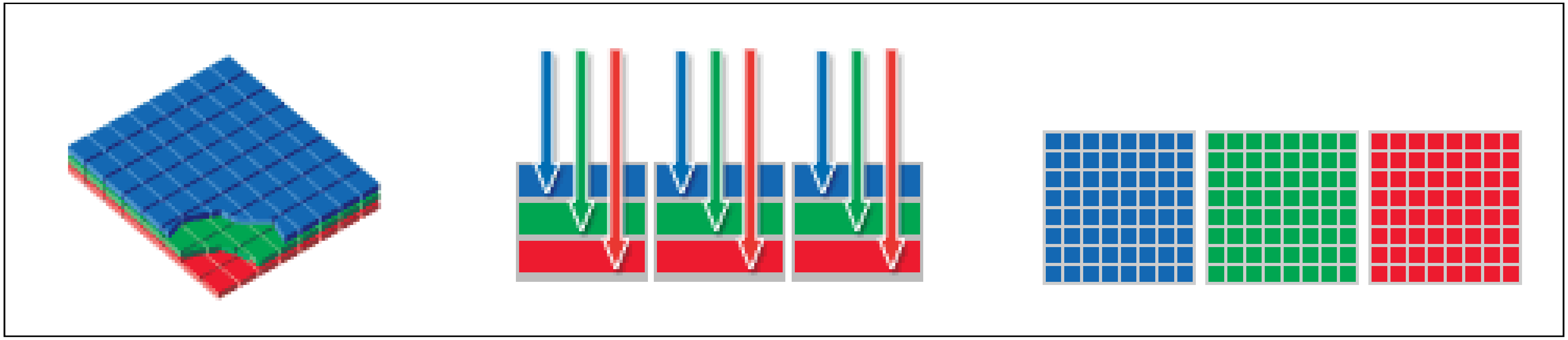
- Perfect debayering filters are still an **ongoing task in research**.
- Good debayering **must be done in a post process**.
- Good camera deliver there the image data in a **RAW format**.
- Applications such a **Adobe LightRoom** or **Apple Aperture** have there own complex debayering algorithms.

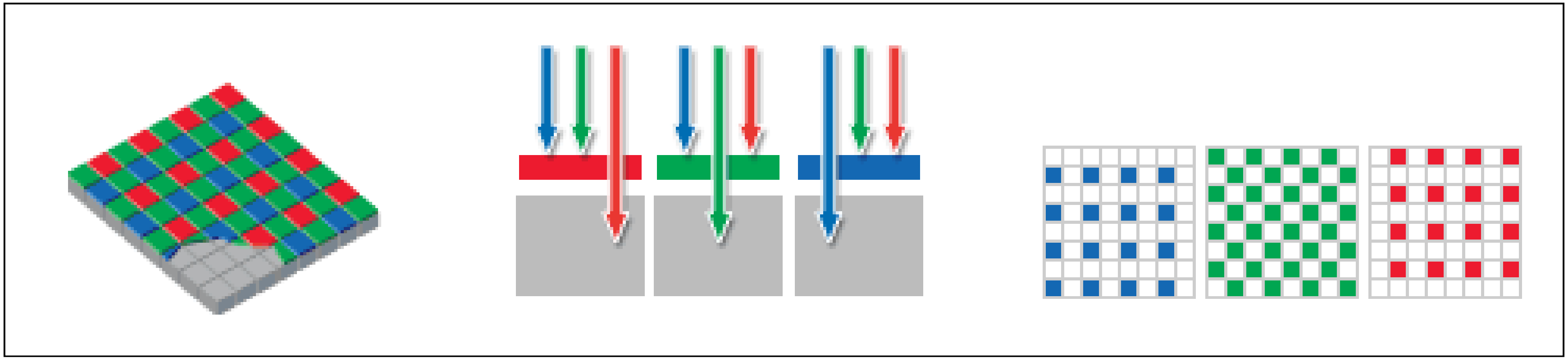
Digital Image Acquisition: Multilayer Color Sensor

- 3 sensitive layers absorb the 3 colors
- No interpolation artefacts.
- Company: Foveon

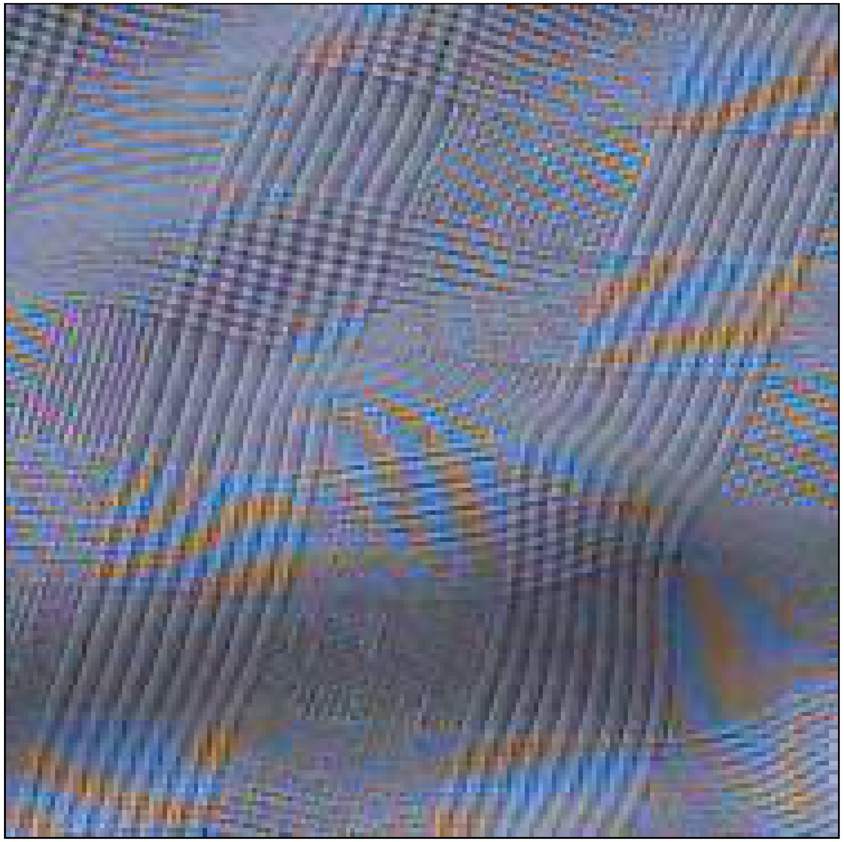


Digital Image Acquisition: Multilayer Color Sensor

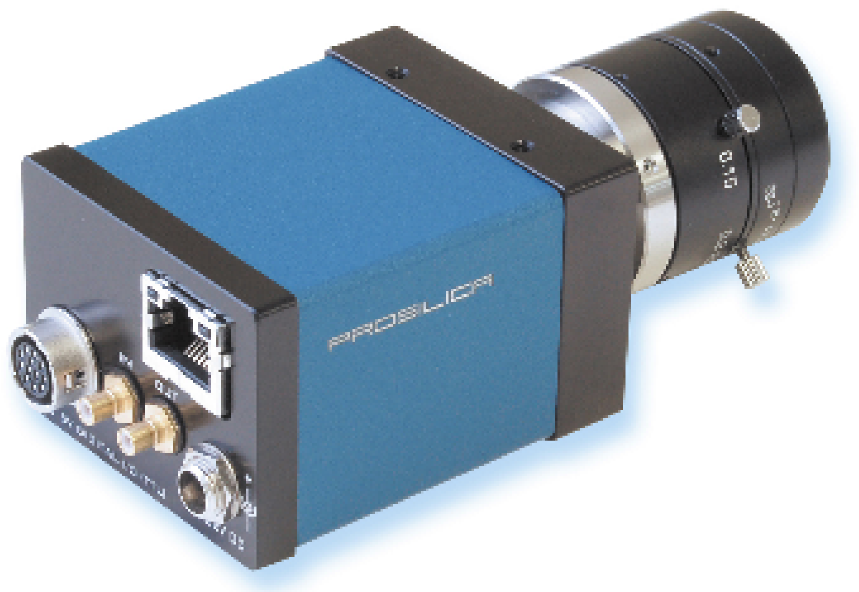


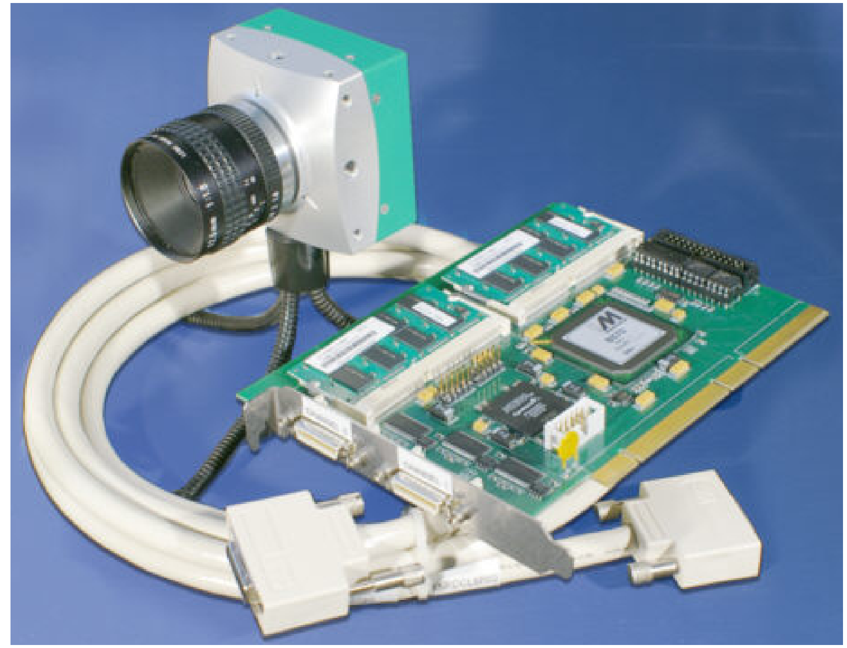


Digital Image Acquisition: Multilayer Color Sensor



Digital Image Acquisition: Camera Interfaces





Digital Image Acquisition: Camera Interfaces

Interface	MByte/s	max. cable length	Frame Grabber	CPU Consumptio n	Advantages / Disadvantages
USB 2.0	30	5m	No	high	popular, slow, short cable, will go away.
Firewire IEEE 1394a	50	15m	No	low	popular, medium fast, needs additional power supply
Firewire IEEE 1394b	80	15m 100m bei 100 MBit	No	low	pretty fast, needs power supply
GigE Vision Gigabit Ethernet	100	100m	No	medium	popular in machine vision, long cable, fast.
USB 3.0	400	5m	No	low	New standard, not yet spread.
Camera Link (CL)	680	10m	Yes	medium	Fasted interface for a long time, needs extra frame grabber
CoaXPress	6250 3125	40m 100m	Yes	?	New standard, fastest interface

Digital Image Acquisition: Exercise in ImageJ

- Debayering in ImageJ: