Image formation
Colour

Vladislav Goncharenko
Senior researcher

girafe ai

MIPT, spring 2024

Revise

Lecture 1:
Biological vision

- Eyes structure and types
- Human eye parameters
- Binocular vision
- Ways to improve eyes performance
- Applications in science and business

Outline

1. Light and colour
2. Camera models
3. Sensors

Some basic definitions

- **Computer vision** (CV) is an interdisciplinary field that deals with how computers can be made to gain high-level understanding from digital images or videos
- **Image processing** and image analysis tend to focus on 2D images, how to transform one image to another, e.g., by pixel-wise operations such as contrast enhancement, local operations such as edge extraction or noise removal, or geometrical transformations such as rotating the image
- **Machine vision** (MV) is the technology and methods used to provide imaging-based automatic inspection and analysis for such applications as automatic inspection, process control, and robot guidance, usually in industry

Light and colour

01

Mathematics of colour

In case of direct light

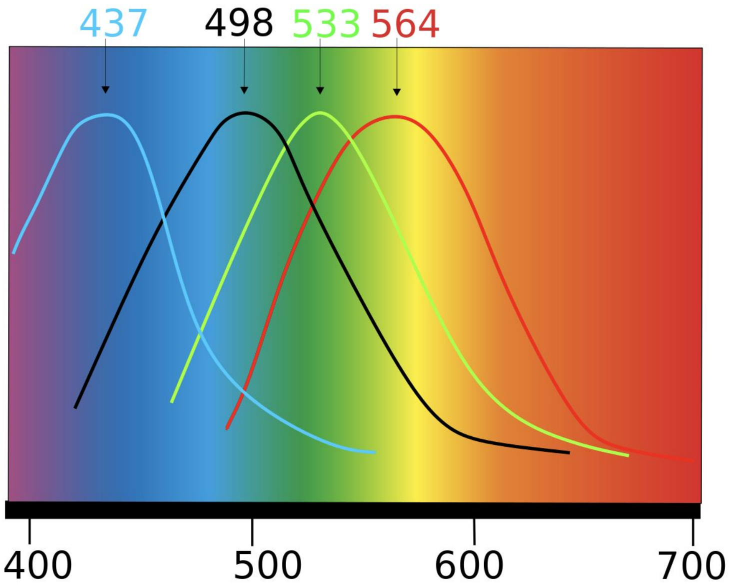
$$S(\lambda) \longrightarrow \chi_i(\lambda)$$

short $\chi_B(\lambda)$

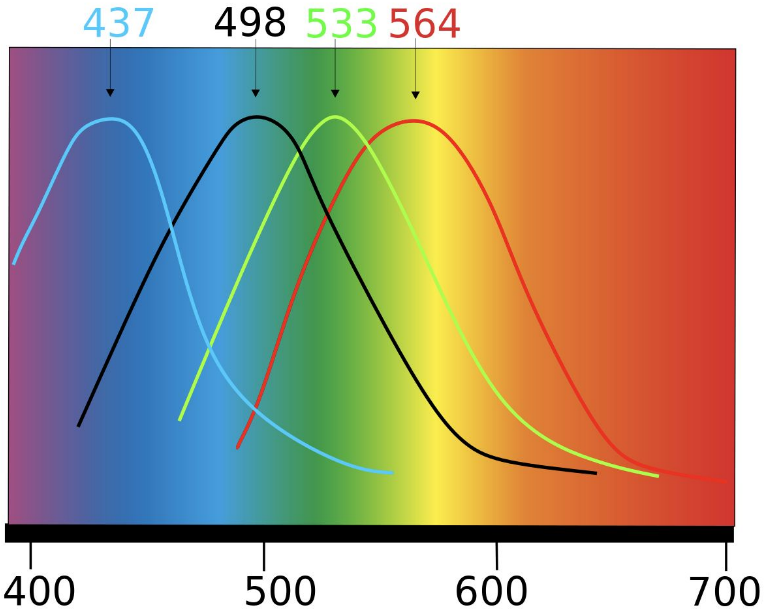
medium $\chi_G(\lambda)$

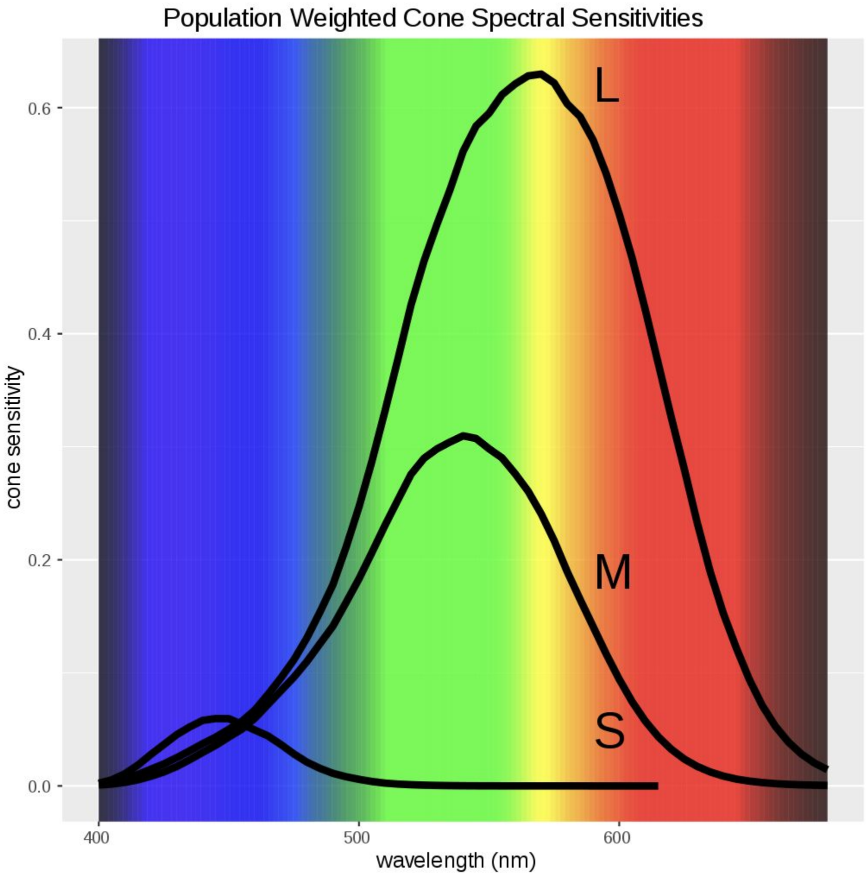
long $\chi_R(\lambda)$

$$\bar{a} = \int_0^\infty S(\lambda)\cdot\bar{\chi}(\lambda)\,d\lambda$$

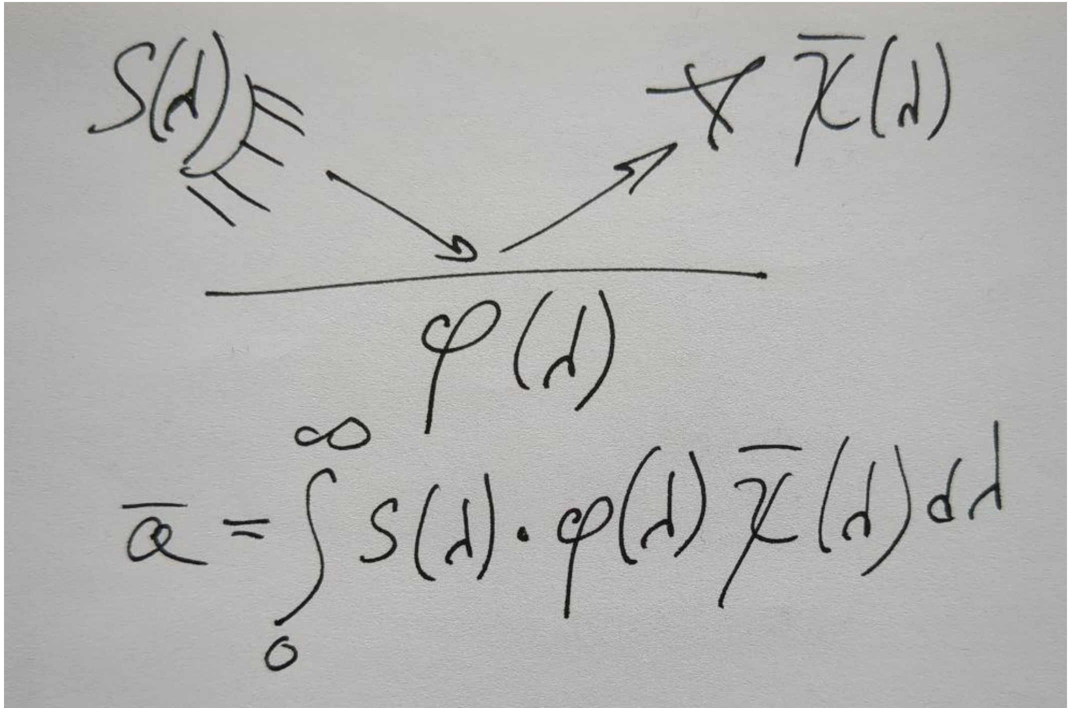


Sensitivity of cones





Reflected light

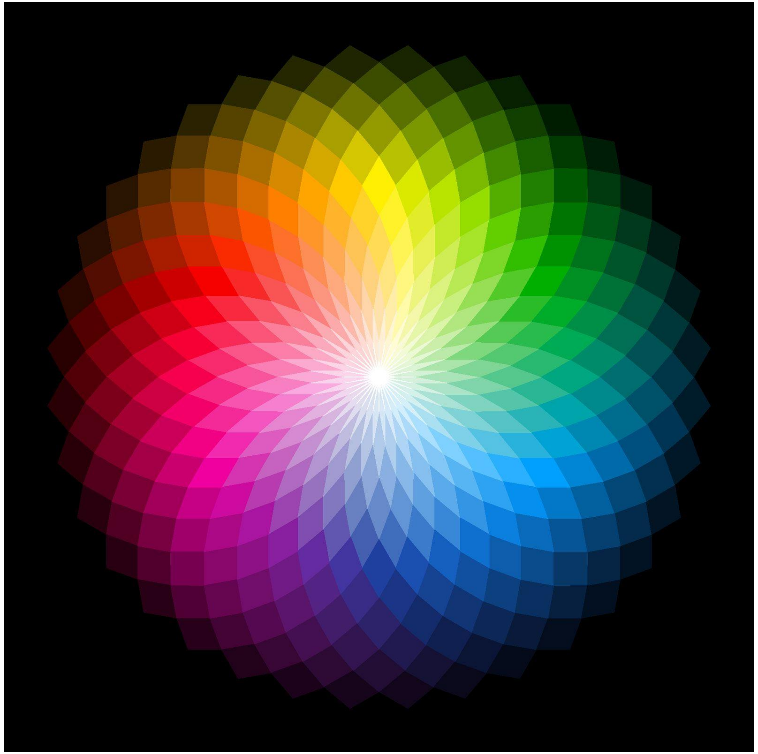


Colour

visual perception based on the electromagnetic spectrum.

One of pioneers of colour theory is Erwin Schrödinger

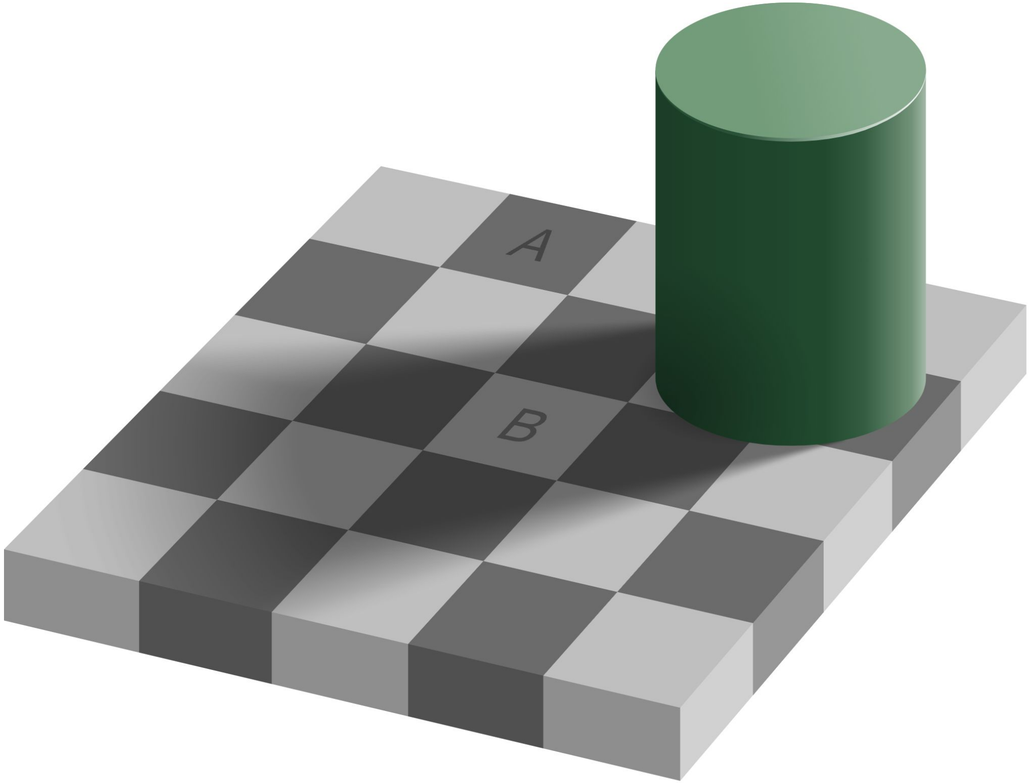
Great lecture on colour theory (Ru)



Color constancy

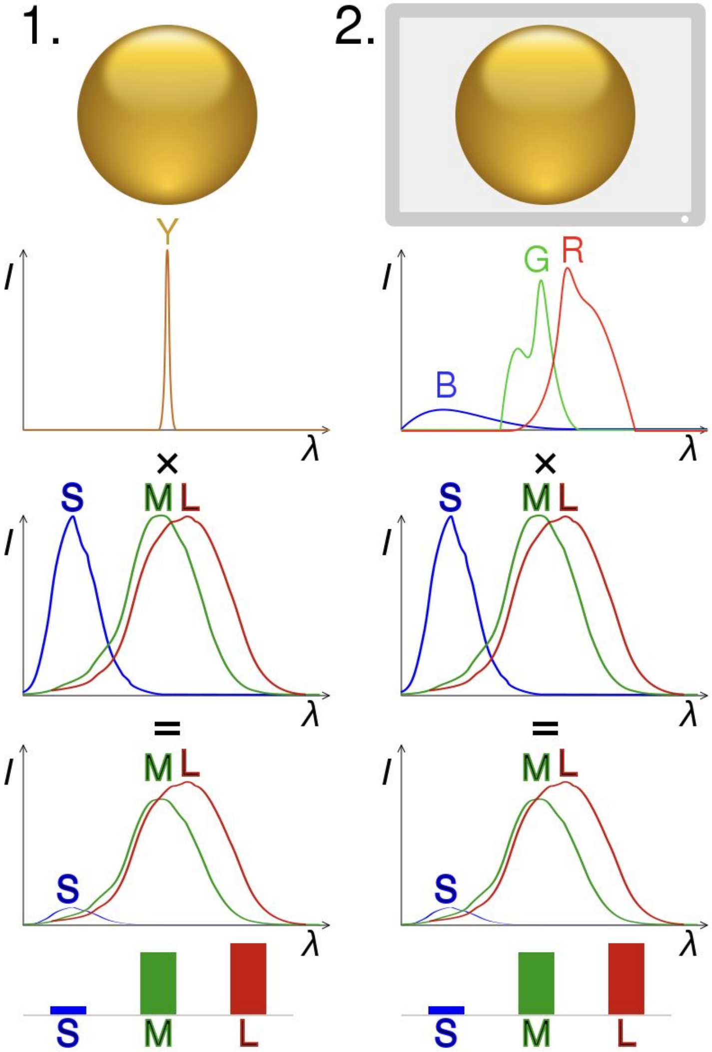
Despite wavelength we infer same colour of A and B

This is hard to achieve!

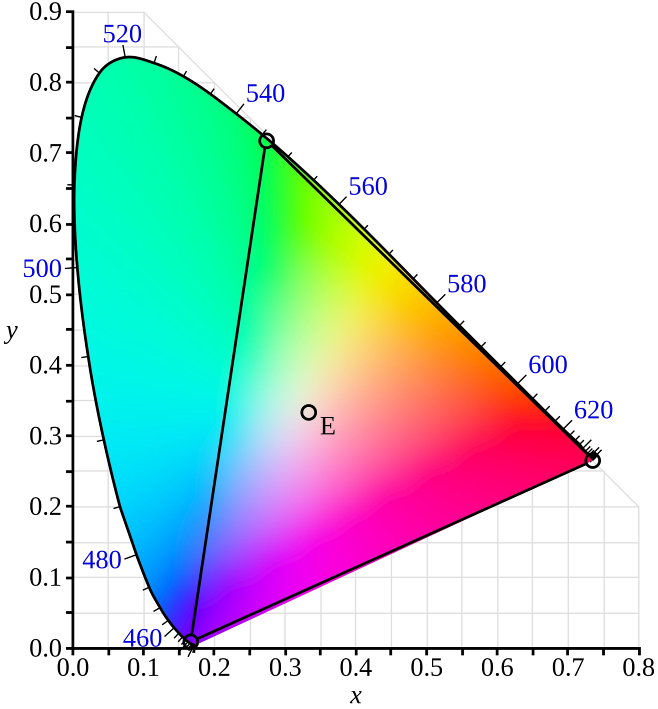


Metamerism

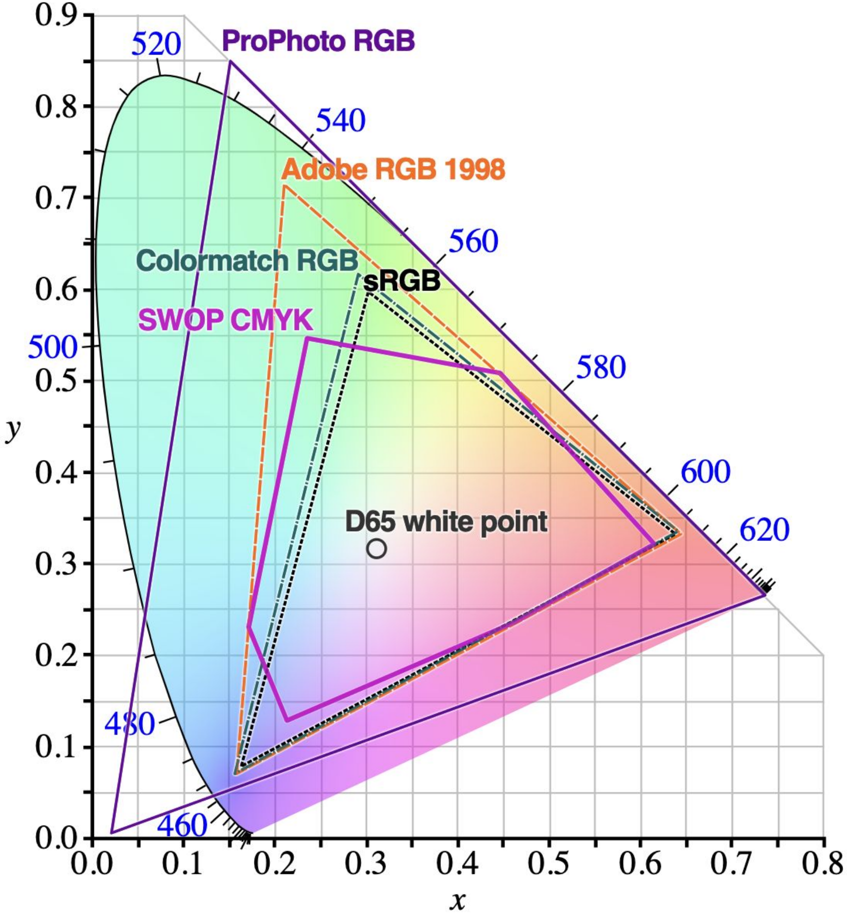
One feeling of colours can be produced by different spectrums



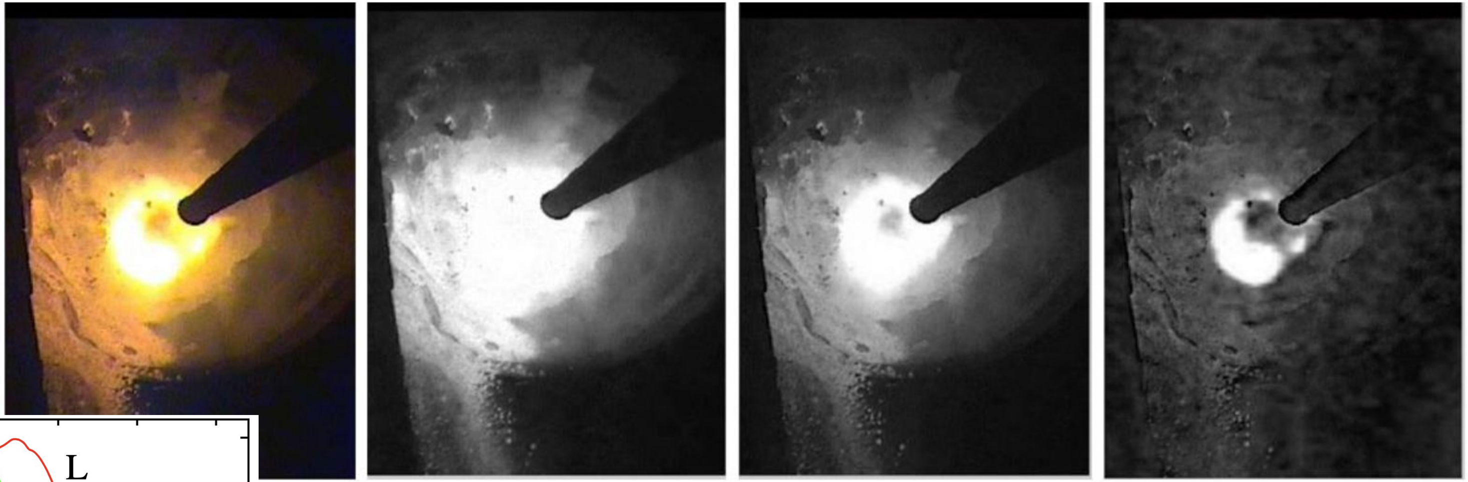
Colour space

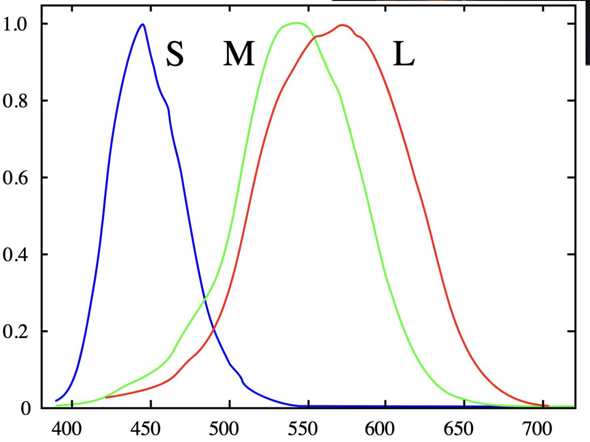


CIE 1931



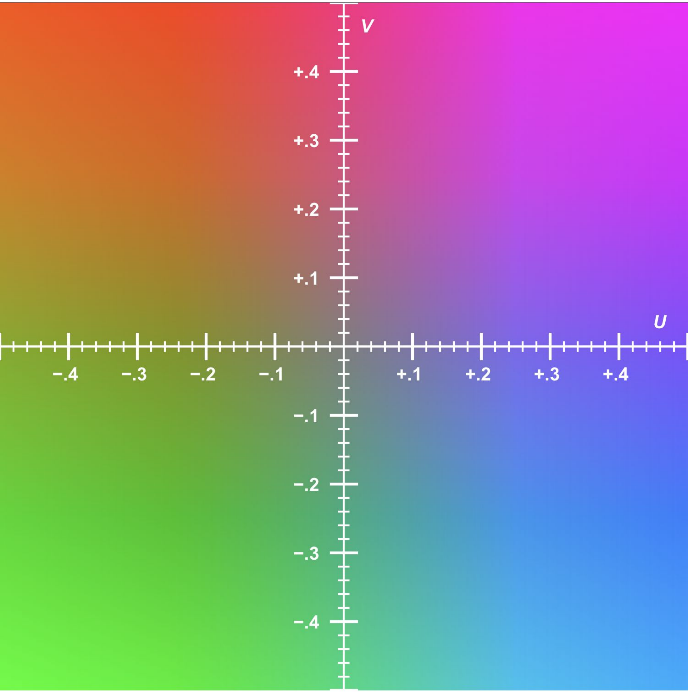
Red Green Blue





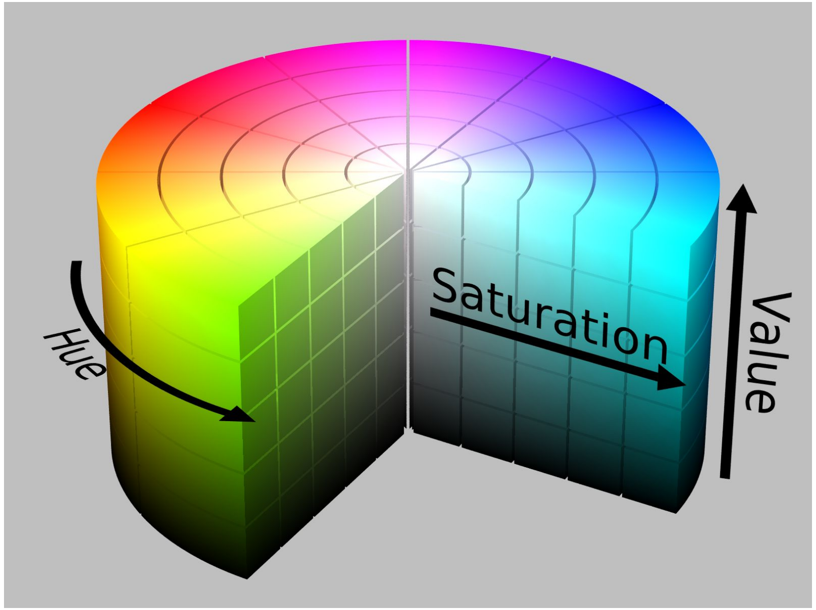
YUV

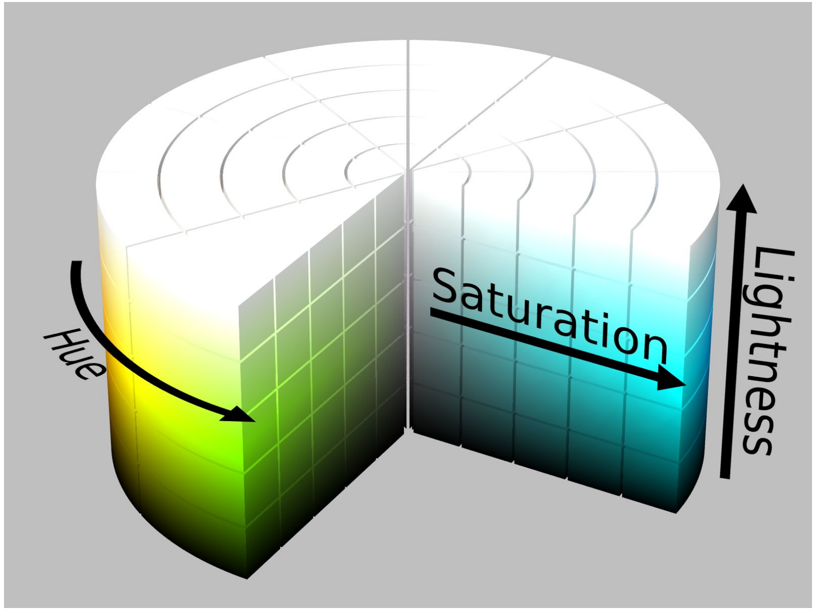
is used in television (analog signal) [wiki]



$$Y = 0.2989 \cdot R + 0.5870 \cdot G + 0.1140 \cdot B,$$
$$U = 0.493\ (B - Y),$$
$$V = 0.877\ (R - Y).$$

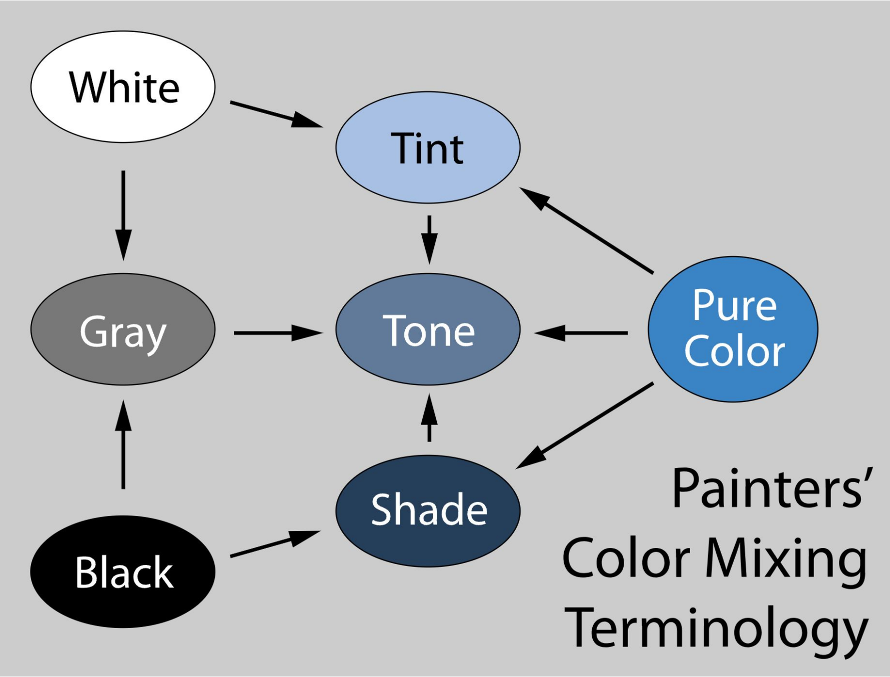
Hue, Saturation, Value (HSV)

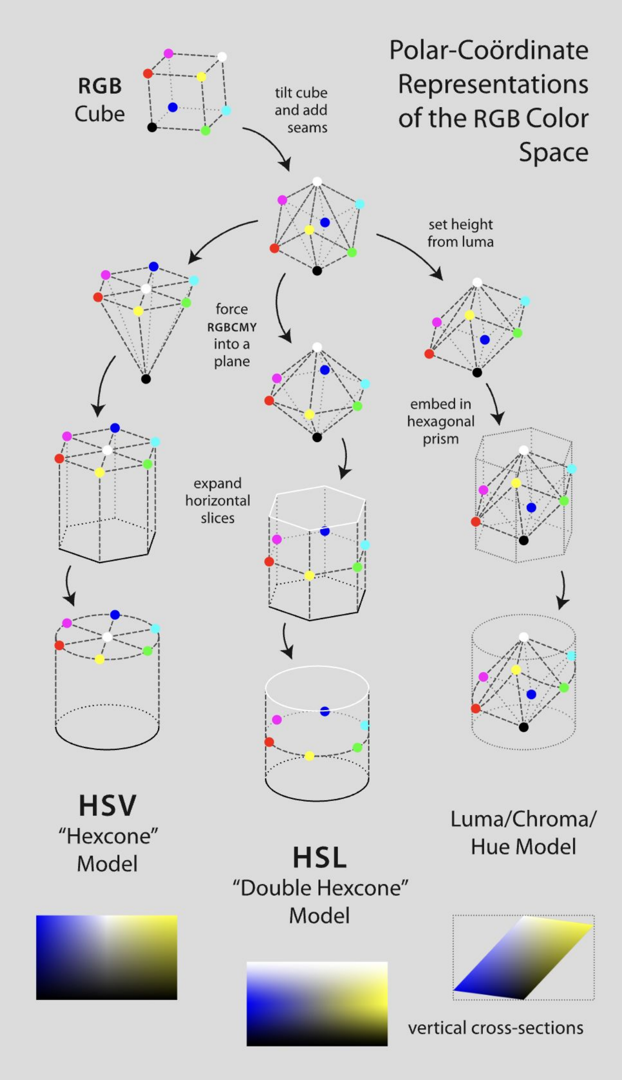




HSV

animation





HSV usage

Fig. 13a. Color photograph (sRGB colorspace).

Fig. 13b. CIELAB L^* (further transformed back to sRGB for consistent display).

Fig. 13c. Rec. 601 luma Y'.

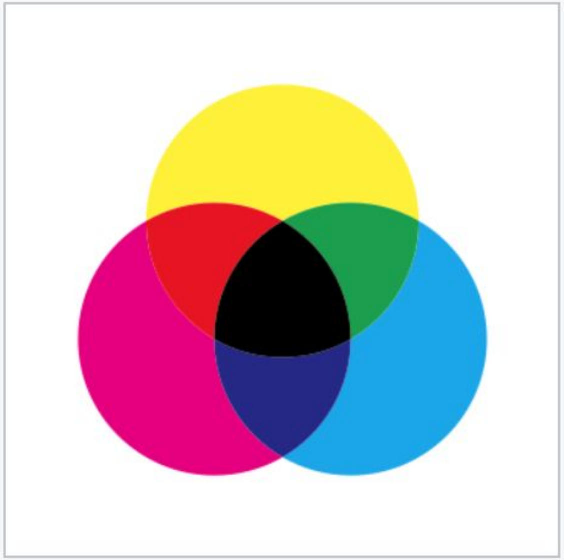
Fig. 13d. Component average: "intensity" I.

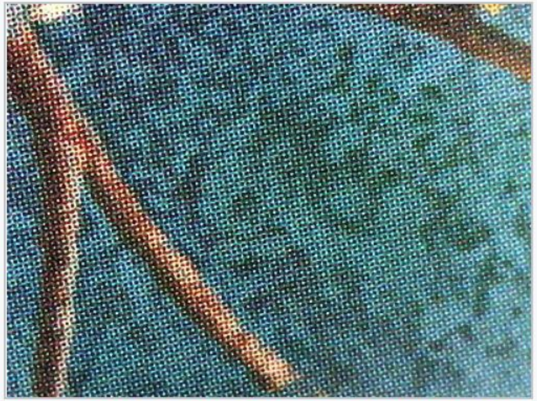
Fig. 13e. HSV value V.

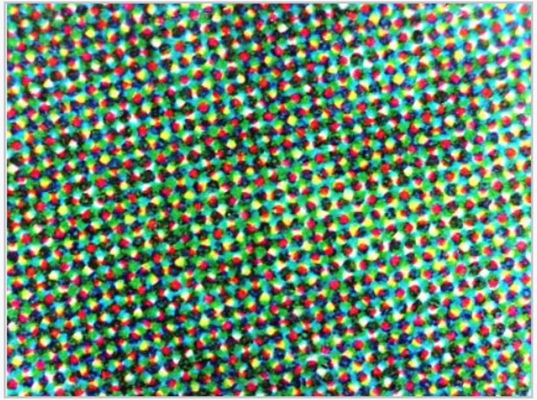
Fig. 13f. HSL lightness L.

CMYK

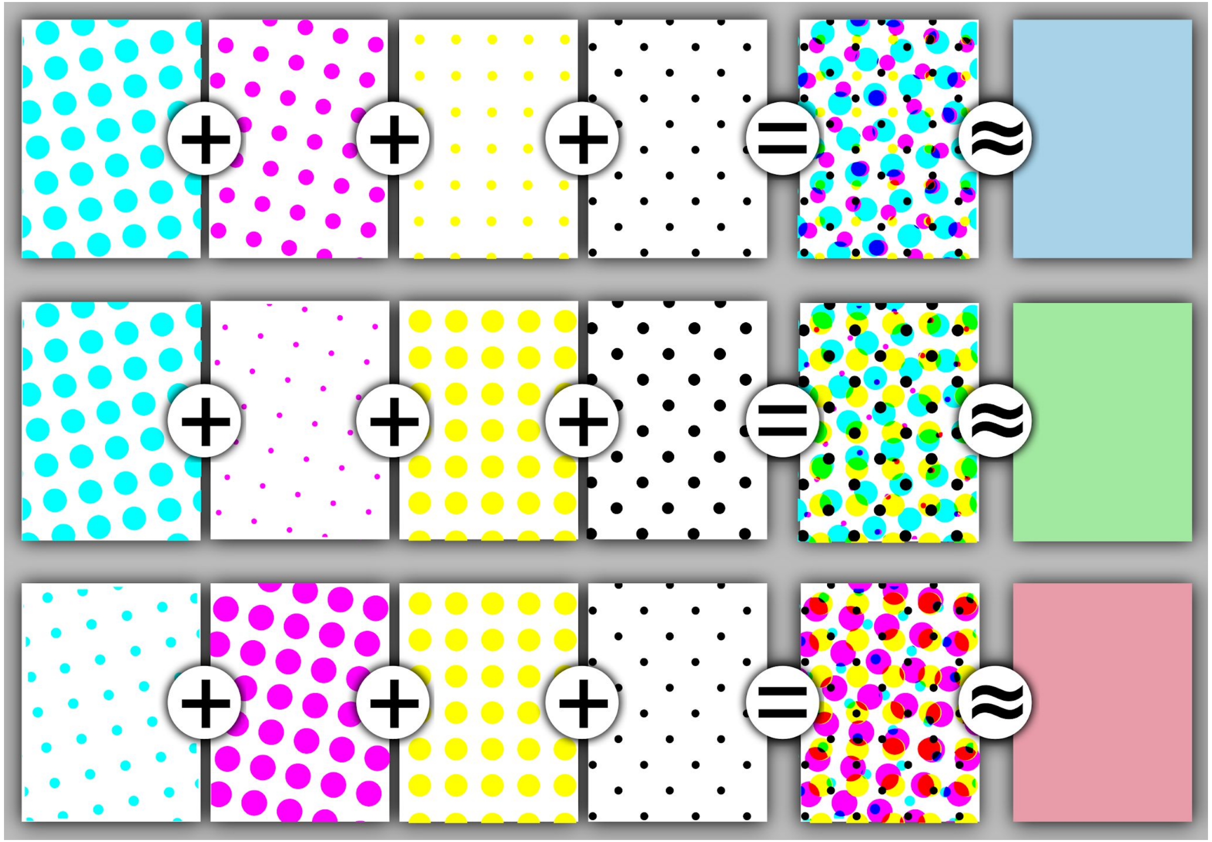
Cyan, Magenta, Yellow, Key (black)



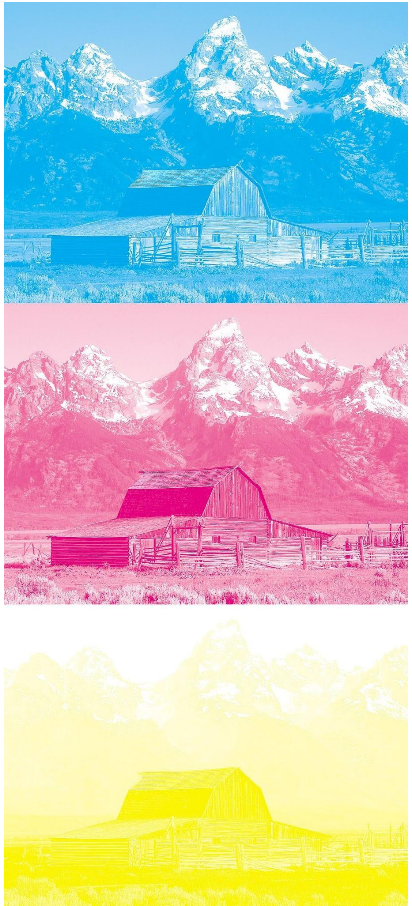


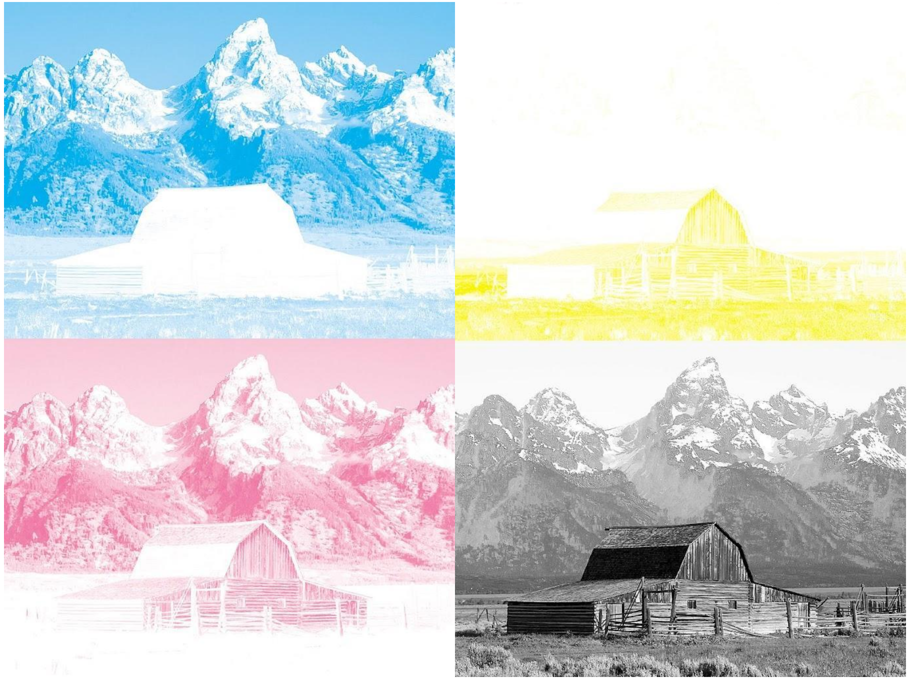


CMYK printing

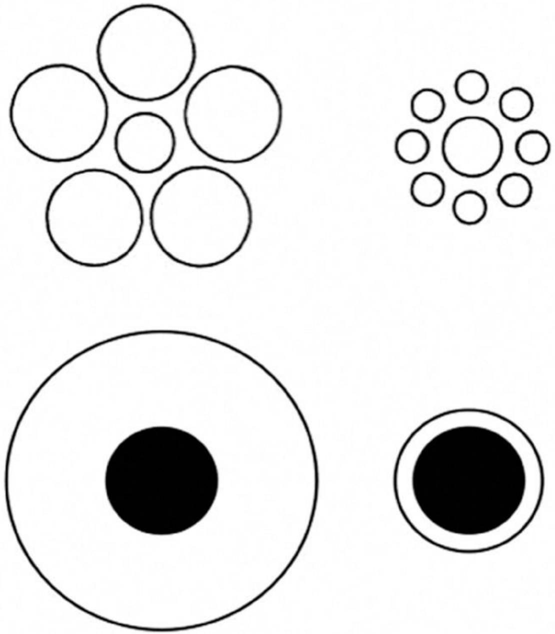


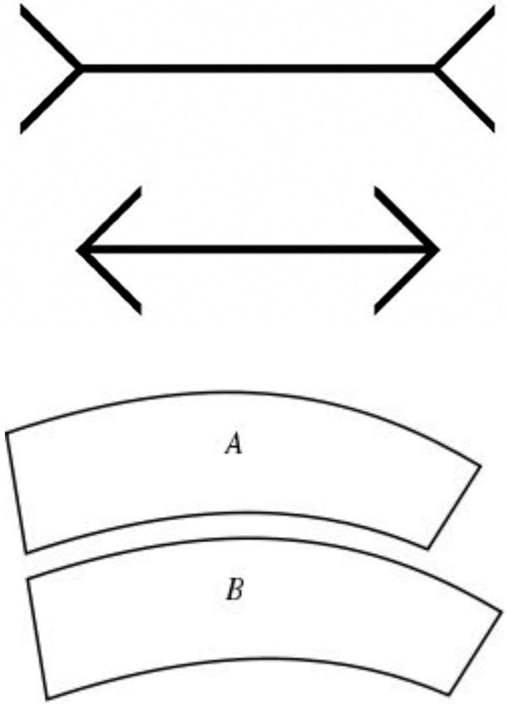
CMYK printing



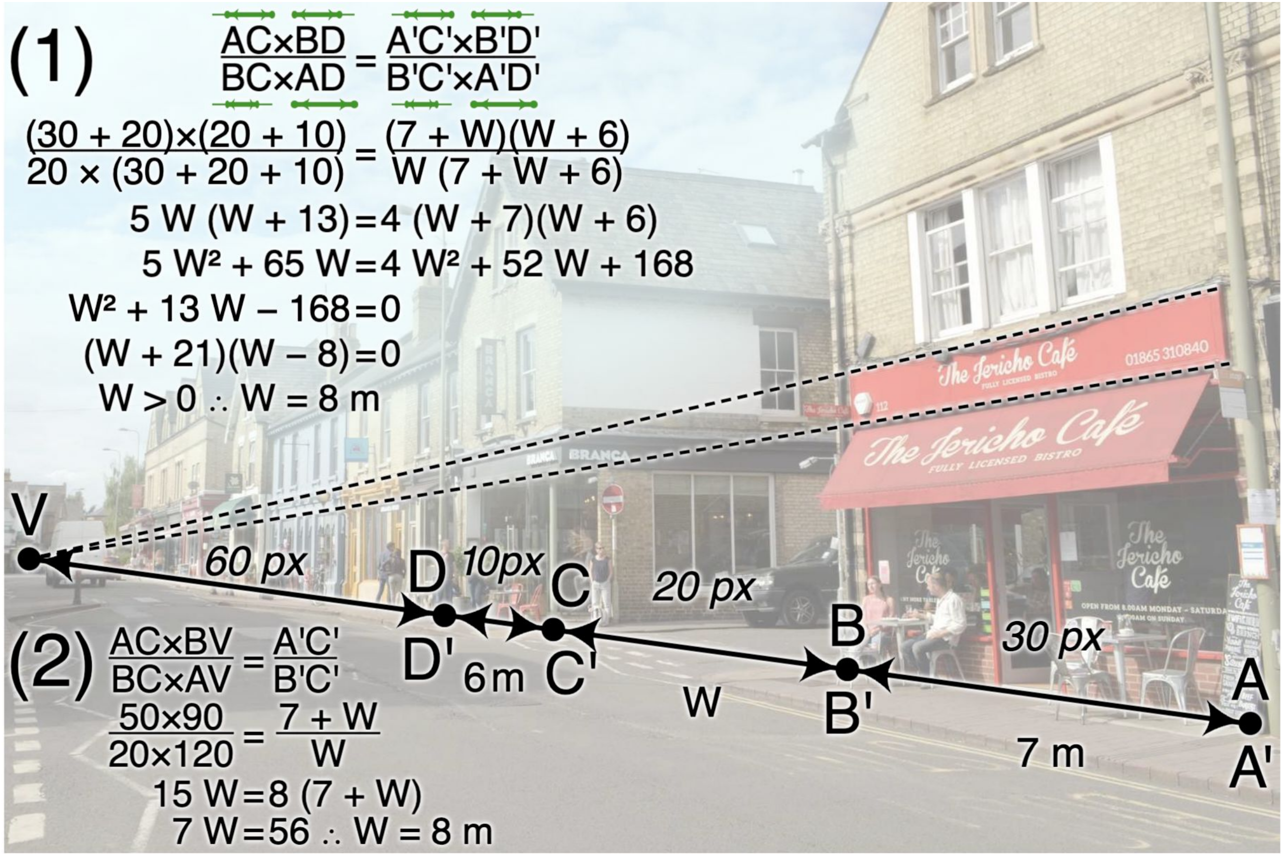


Size estimation





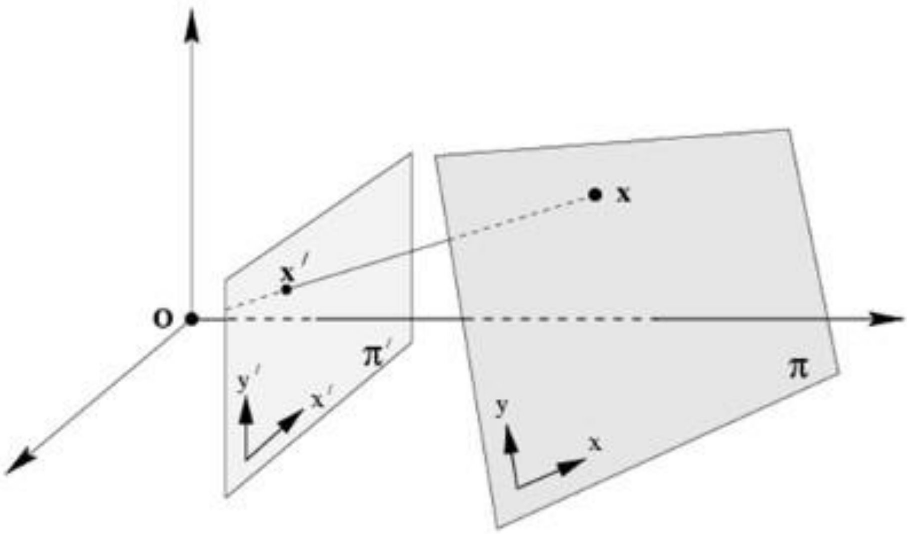
Perspective



Homography

The homography matrix is a 3x3 matrix but with 8 DoF (degrees of freedom) as it is estimated up to a scale.

It is generally normalized with $h_{33}=1$



$$s\begin{bmatrix} x' \\ y' \\ 1 \end{bmatrix} = \mathbf{H}\begin{bmatrix} x \\ y \\ 1 \end{bmatrix} = \begin{bmatrix} h_{11} & h_{12} & h_{13} \\ h_{21} & h_{22} & h_{23} \\ h_{31} & h_{32} & h_{33} \end{bmatrix}\begin{bmatrix} x \\ y \\ 1 \end{bmatrix}$$

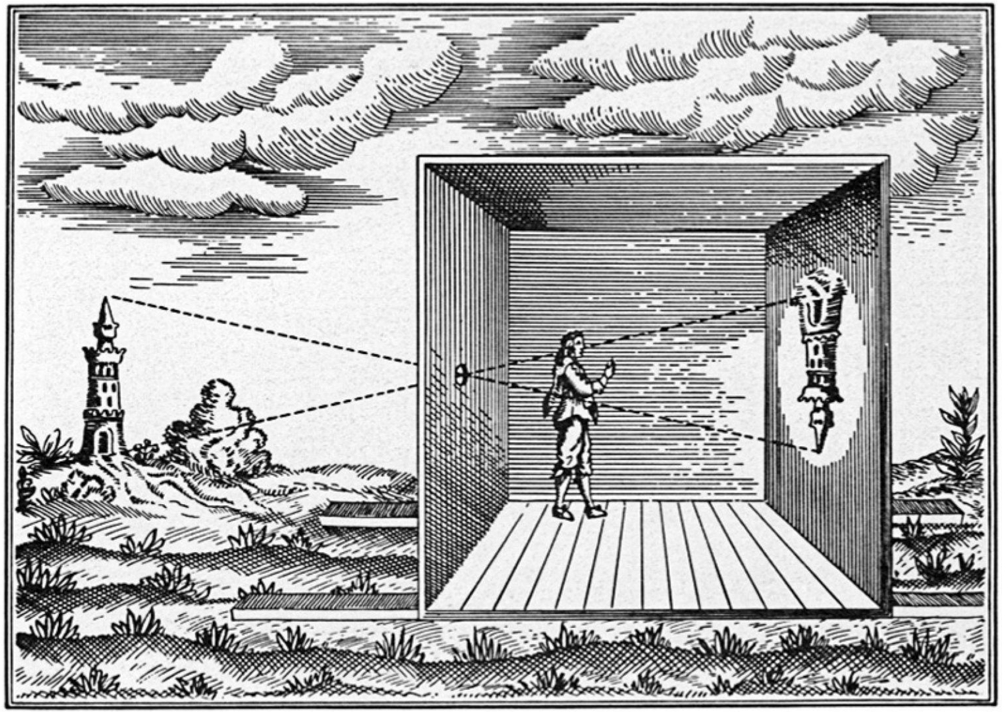
Camera models

girafe
ai

02

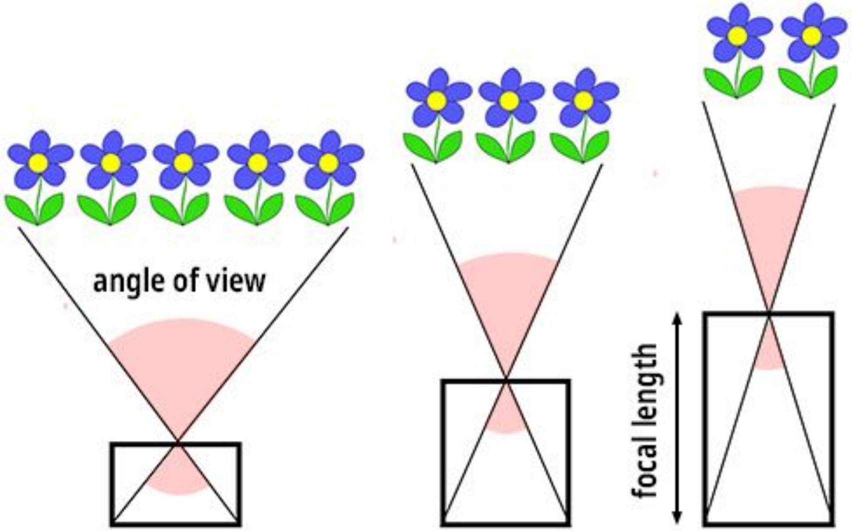
Camera obscura

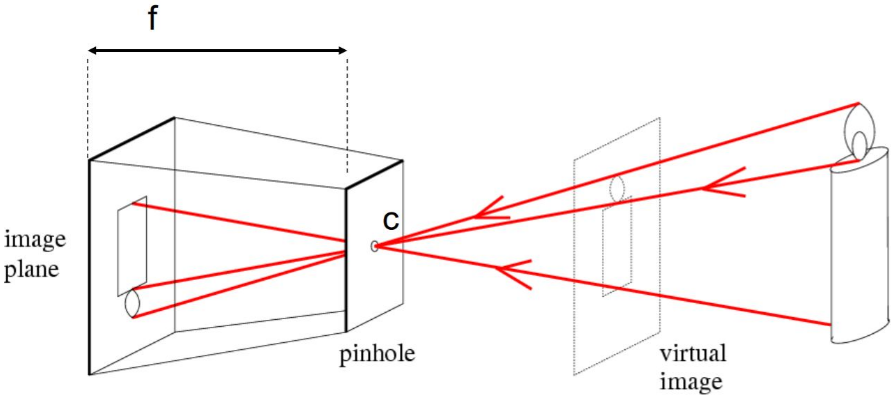
- from Latin camera obscūra - dark chamber
- used since 500 BC



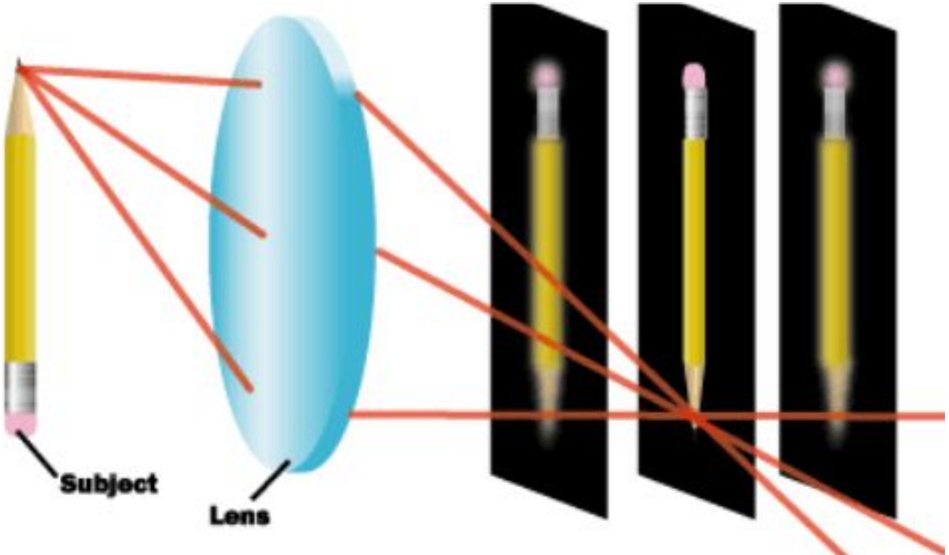
Pinhole camera model

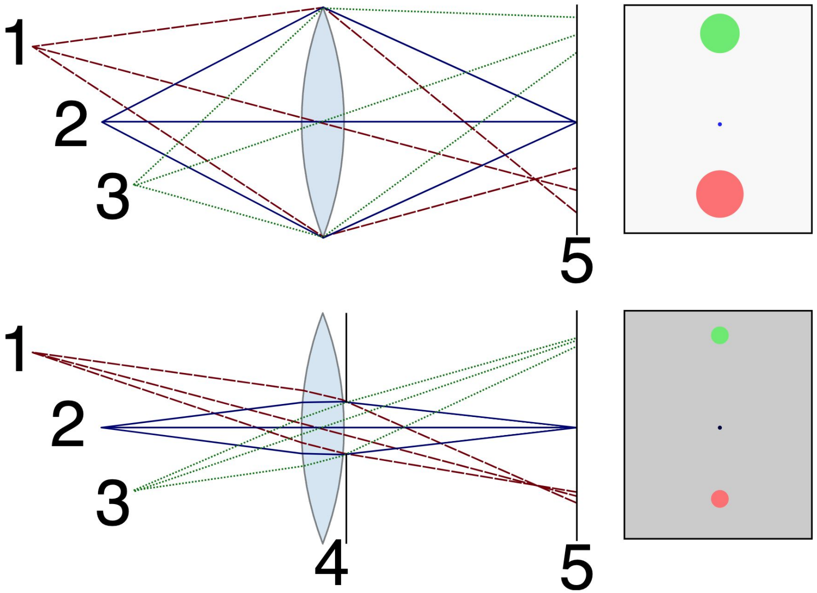
Light don’t refract





Single lens camera





Depth of field

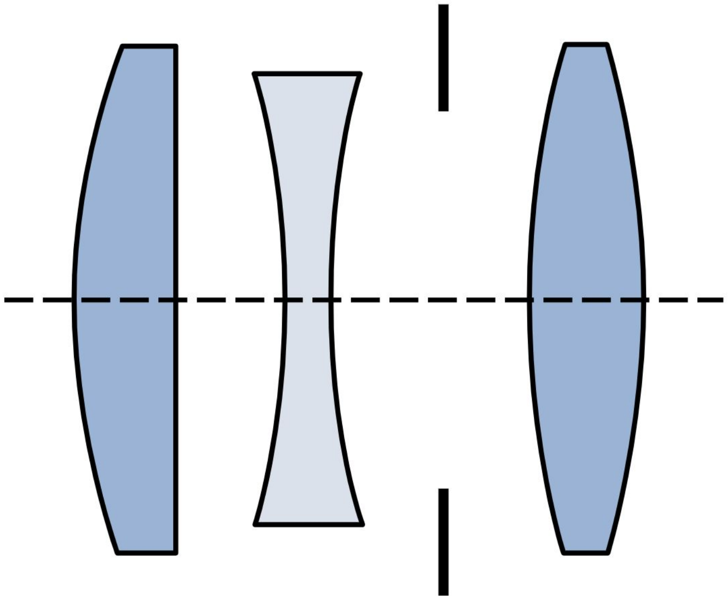
distance between the nearest and the furthest objects that are in acceptably sharp focus in an image captured with a camera

Aperture = *f*/1.4. DOF = 0.8 cm

Aperture = *f*/4.0. DOF = 2.2 cm

Aperture = *f*/22. DOF = 12.4 cm

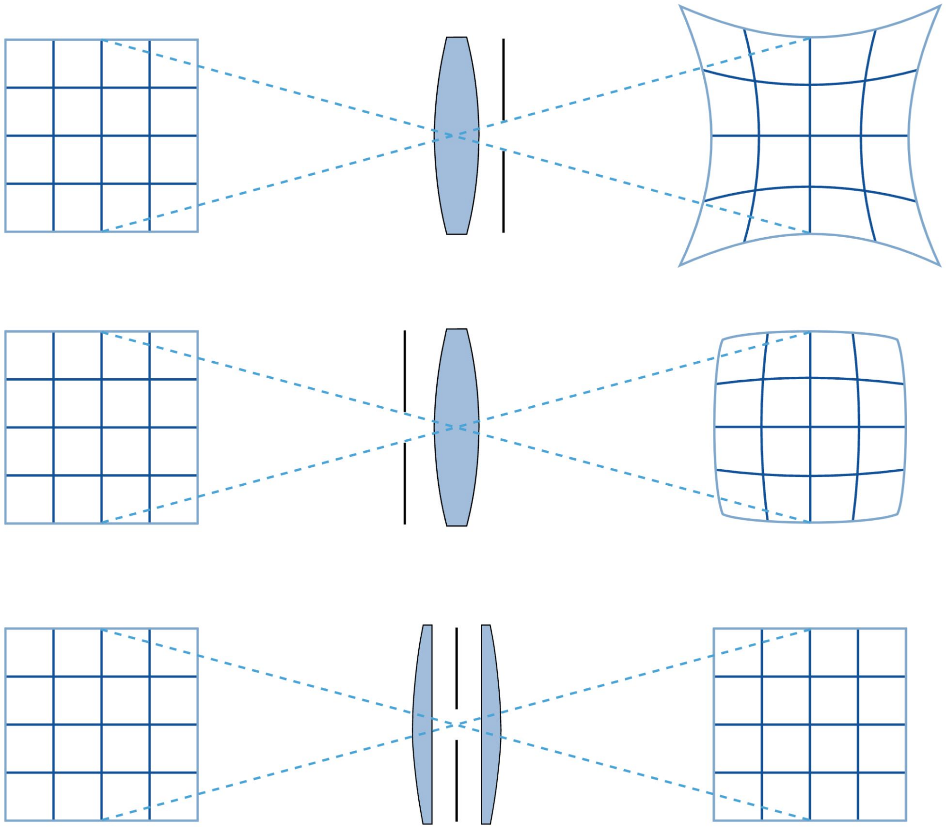
Compound lenses



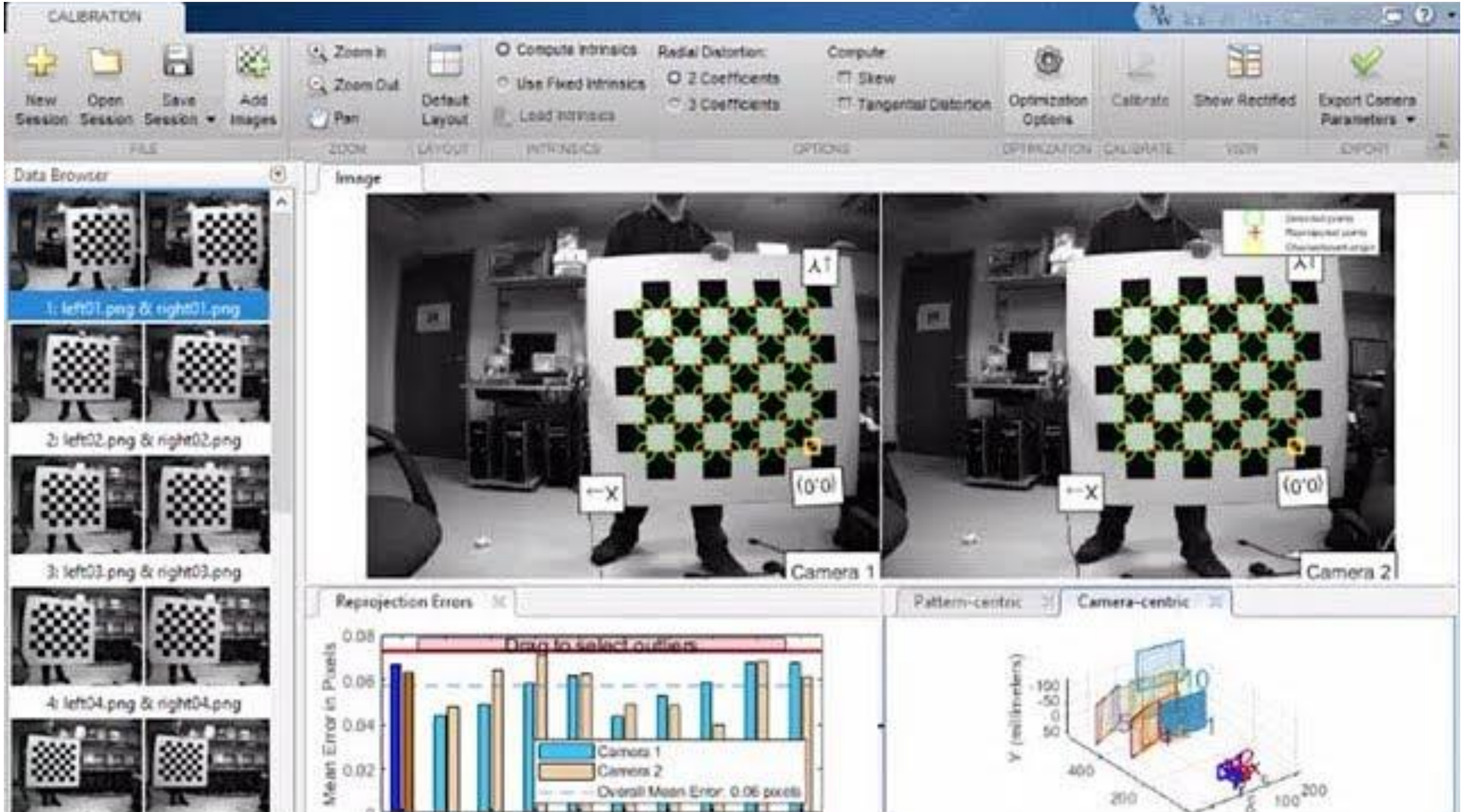
triplet lens

Distortion

Distortion

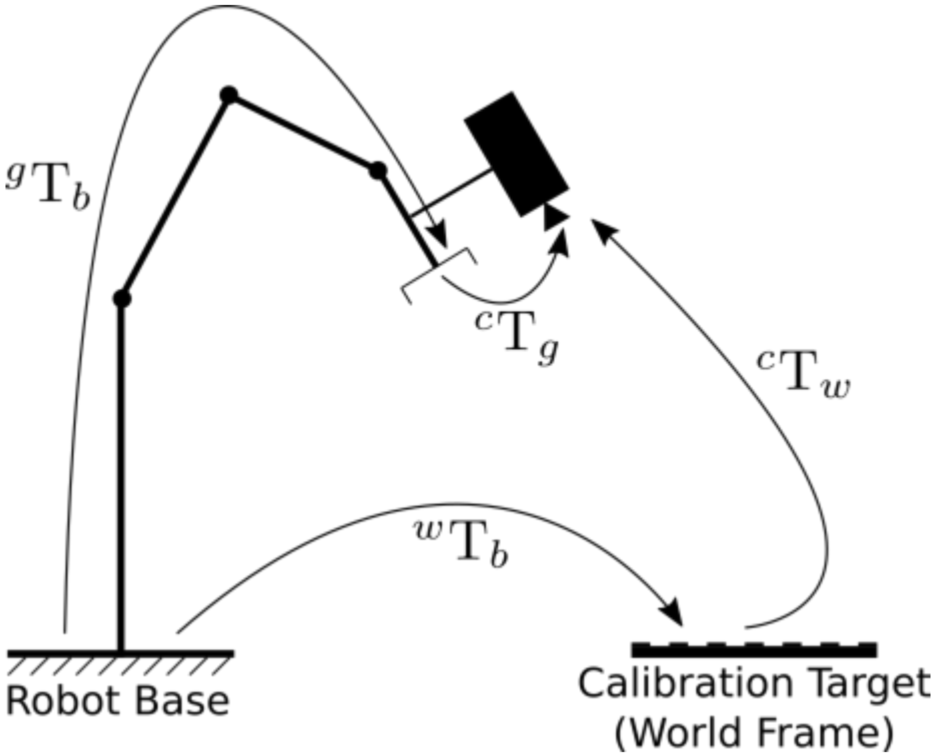


Camera resectioning



Camera model in OpenCV

Documentation



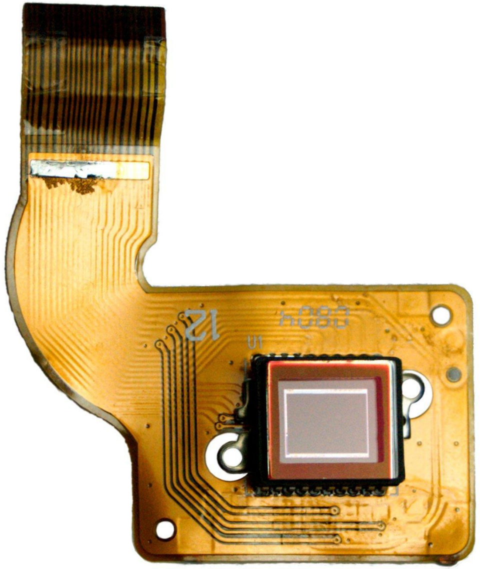
Sensors

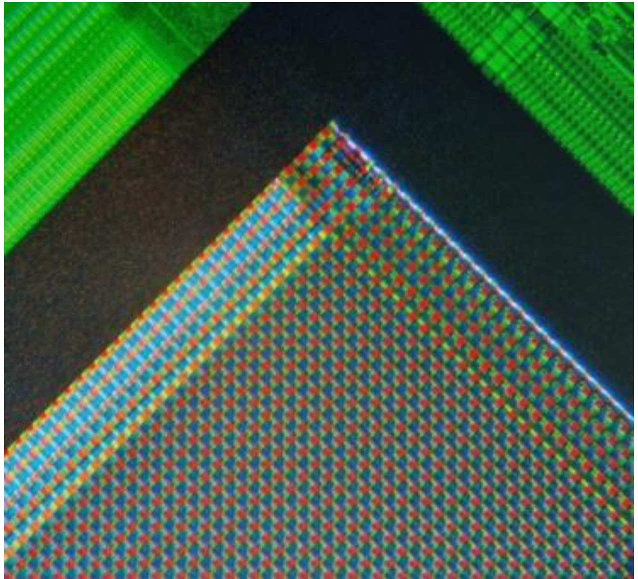
girafe
ai

03

Image sensor

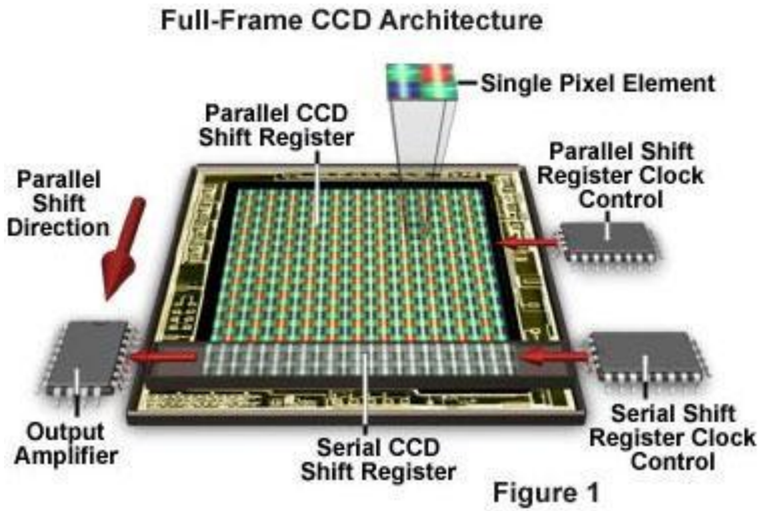
is a sensor that detects and conveys information used to form an image. It does so by converting the variable attenuation of light waves (as they pass through or reflect off objects) into signals, small bursts of current that convey the information

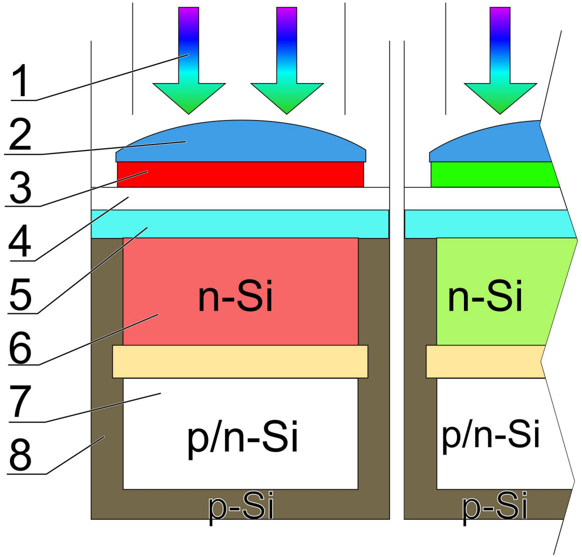




Charge-coupled device

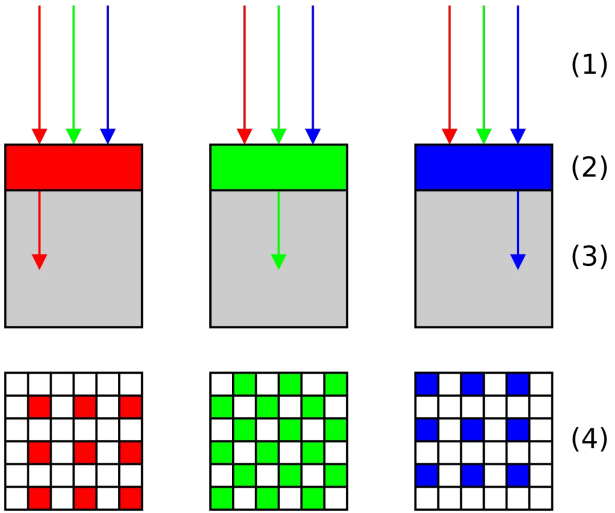
- The charge-coupled device (CCD) was invented by Willard S. Boyle and George E. Smith at Bell Labs in **1969**
- in **2009** they were awarded the Nobel Prize for Physics[20] for their invention of the CCD concept

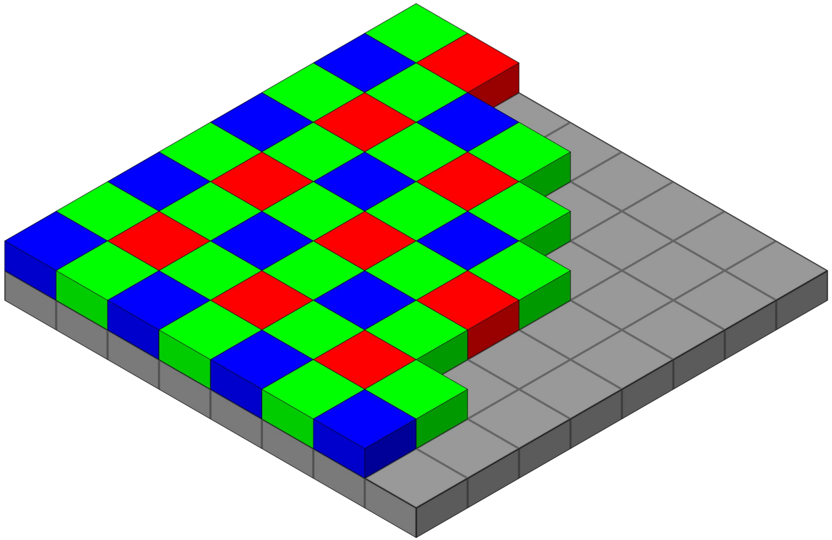




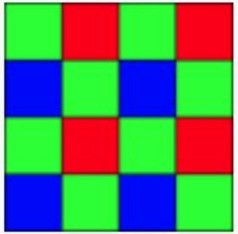
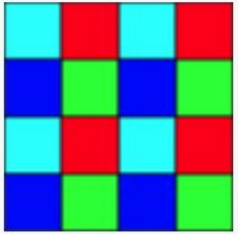
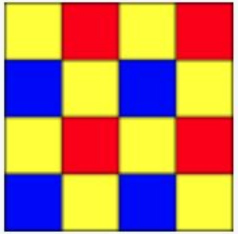
Bayer filter

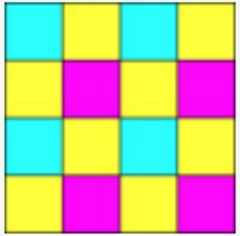
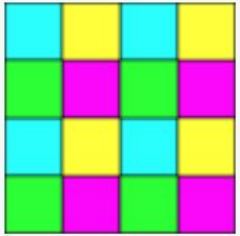
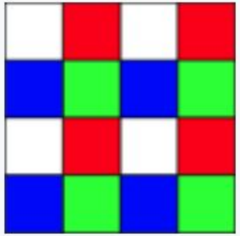
is a **color filter array (CFA)** for arranging RGB color filters on a square grid of photosensors. Its particular arrangement of color filters is used in most single-chip digital image sensors used in digital cameras, camcorders, and scanners to create a color image. First patented in 1976



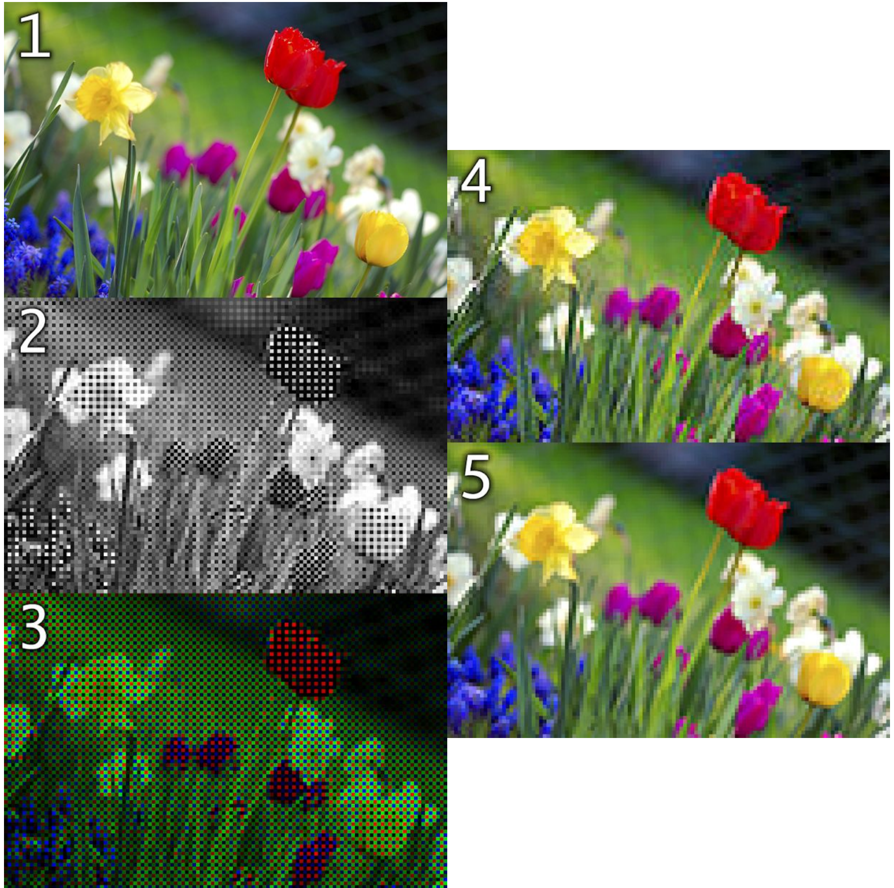


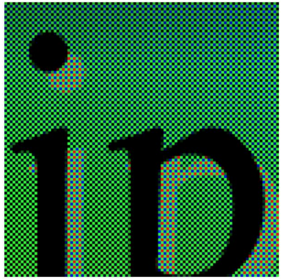
Different color filter arrays

	Bayer filter
	RGBE filter
	RYYB filter

	CYYM filter
	CYGM filter
	RGBW Bayer

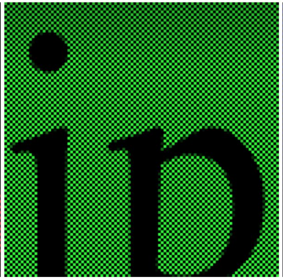
Demosaicing aka debayering





Bayer filter samples

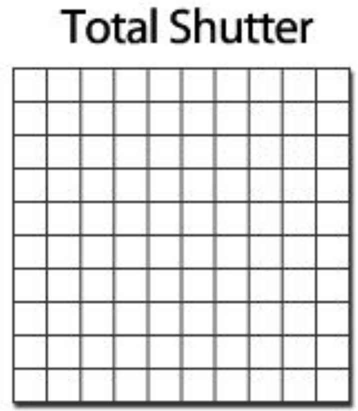
Red



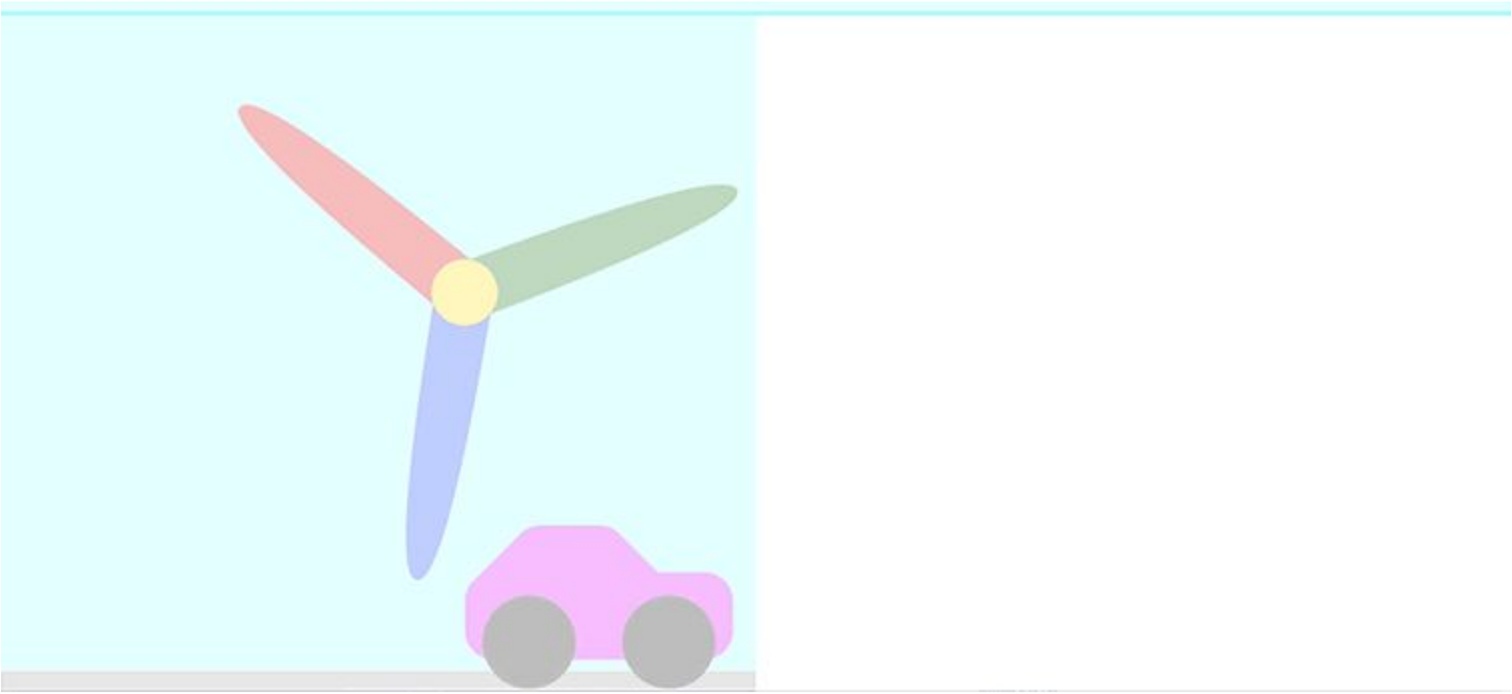
Green

Blue

Camera shutter



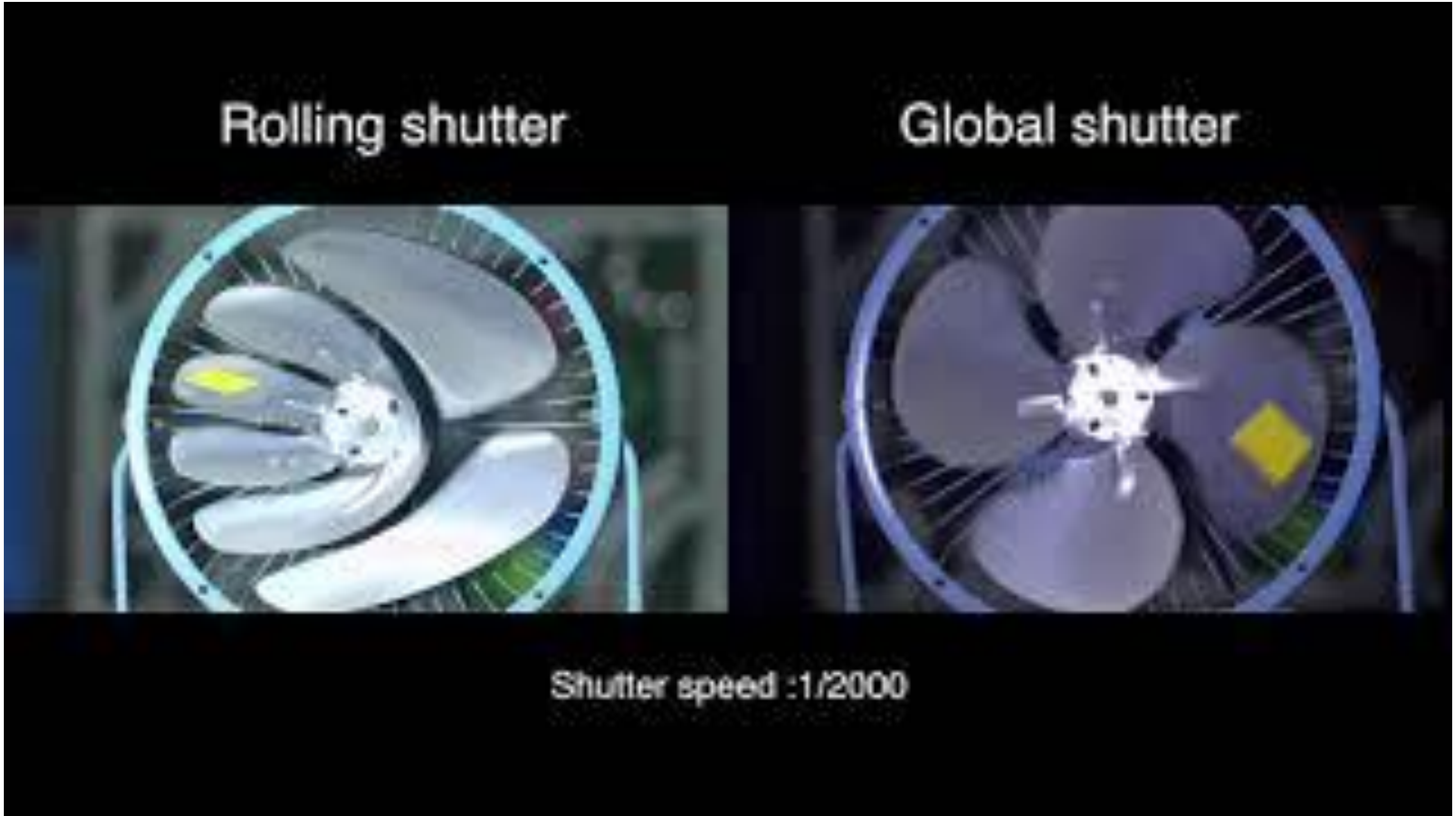
Rolling shutter



Comparison

[video link]

Frequency influence



video link

Camera shutter

Сравнительная таблица плюсов и минусов

Режим	Rolling Shutter	Global Shutter
Снимок экспозиции	нет	да
Порядок считывания	Нет — очень разная «временная» последовательность воздействия	Да — чрезвычайно похожая последовательность воздействия
Временная задержка между различными регионами изображения области	Нет — разница до 10 мс (560 МГц) между центром и верхом или низом изображения	Да — все пиксели представляют одинаковое время экспозиции.
Возможность синхронизации	Комплекс для синхронизации. Требуется источник стробоскопического света. Более длительное время цикла.	Просто синхронизировать. Любой источник света. Более короткое время цикла.
Быстрая двойная экспозиция	нет	да
Максимальная частота кадров	Максимально доступно (не синхронизировано).	Максимальная частота кадров уменьшается вдвое.
Шум	Низкий уровень в районе 1 e^- до 1,3 e^-	Более высокий уровень в районе 2,3 e^- до 2,6 e^-
Искажения,артефакты	Возможны	Нет
Эффективность рабочего цикла	Уменьшено, например, если требуется отключить подсветку во время «переходных» фаз считывания	Как правило, намного больше, так как не требуется переходной фазы считывания.

https://cctvlens.ru/publications/global-shutter-vs-rolling-shutter-podrobnyj-razbor/

Revise

1. Light and colour
2. Camera models
3. Sensors

Thanks for attention!

Questions?

girafe
ai