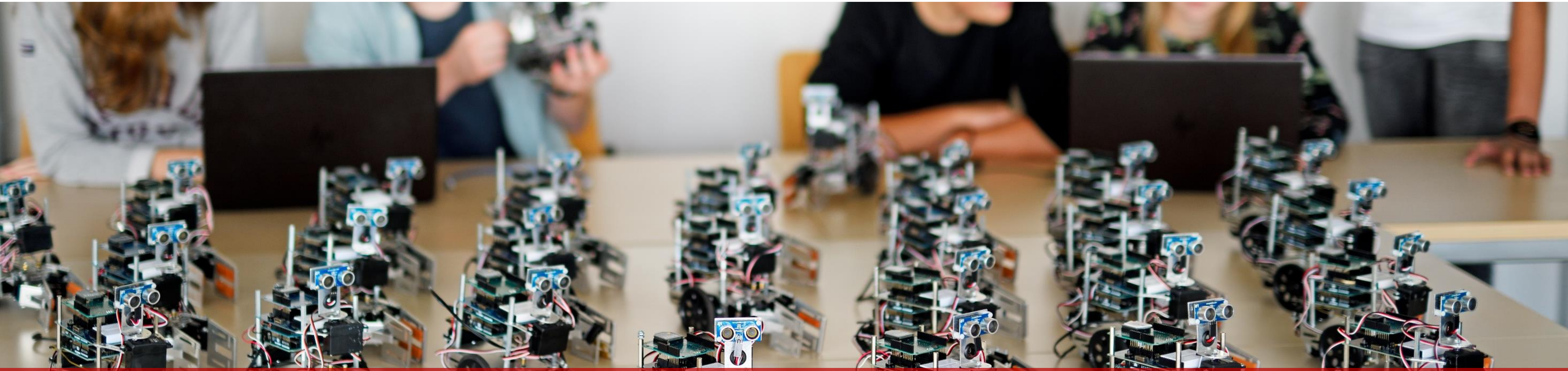


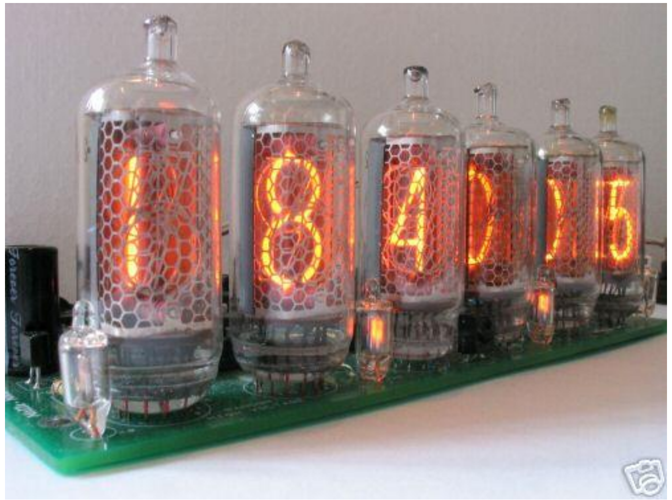
Sensing, Computing, Actuating

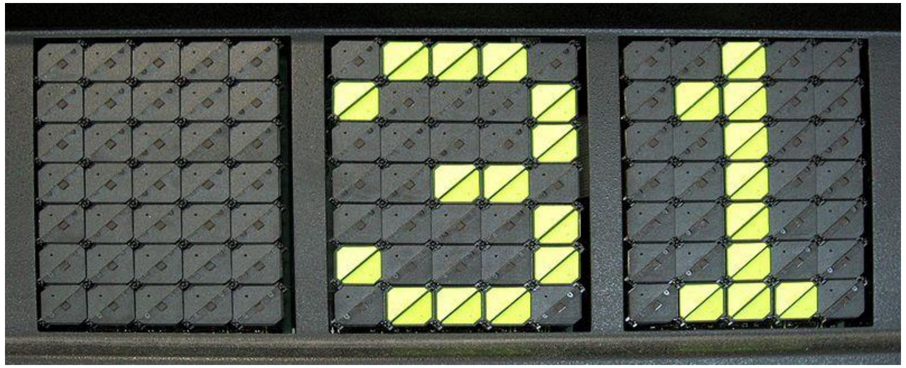
Sander Stuijk (s.stuijk@tue.nl)

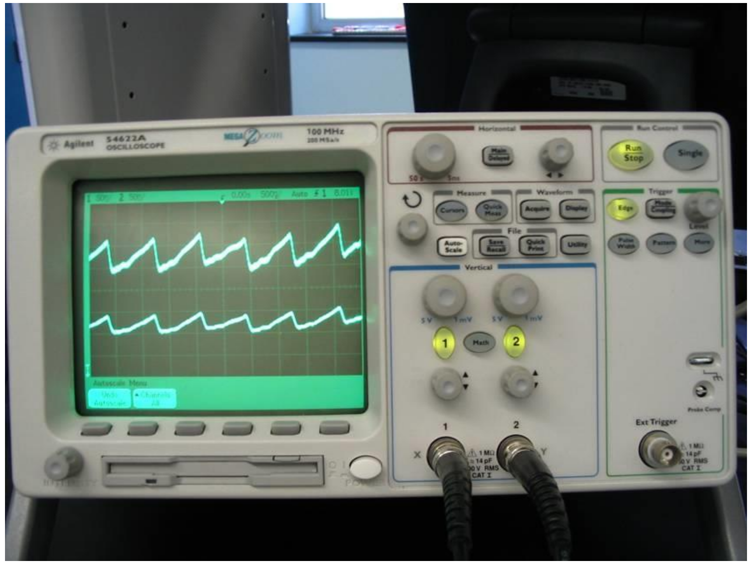
DISPLAYS

(not covered in the book, slide courtesy of Gerard de Haan)

Displays







Emissive matrix-type display

We need an array of lamps that we can control individually:

- Can we make them small enough?
- A lot of dimmers…
- What about color? Separate lamp for every color?
- Will they react quickly enough?

Yes, we can! It is called an LED display

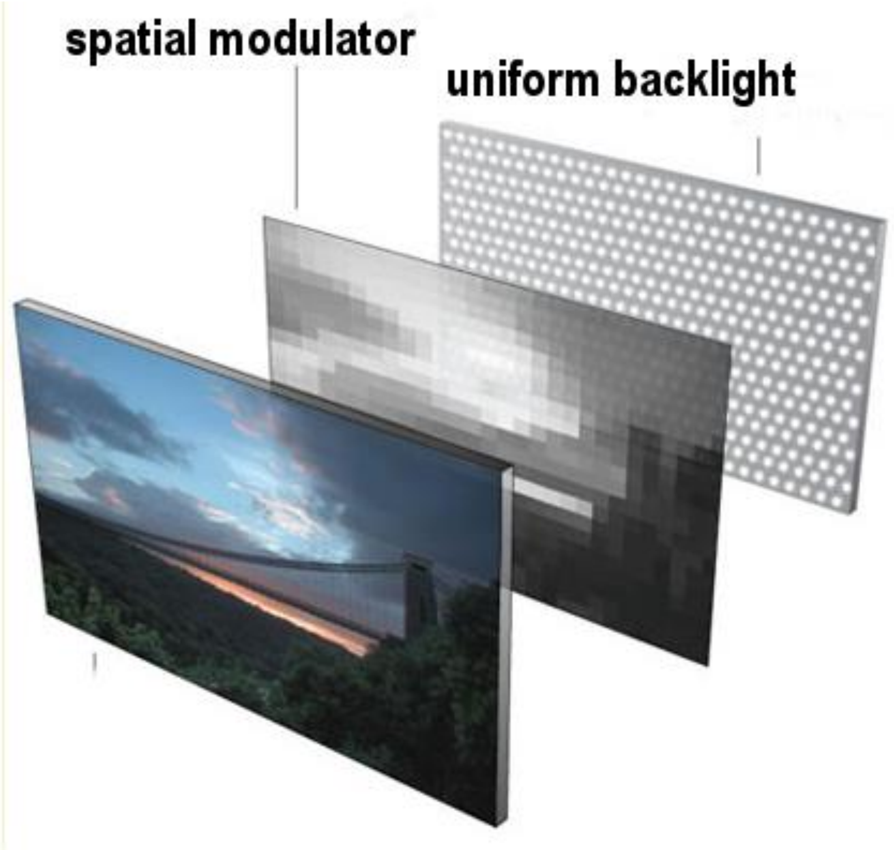
The LED display

Huge array of individual solid-state lamps

Screen detail

Not necessarily emissive…

With a physical phenomenon that allows us to modulate the transparency of a layer we do not need many individual lamps

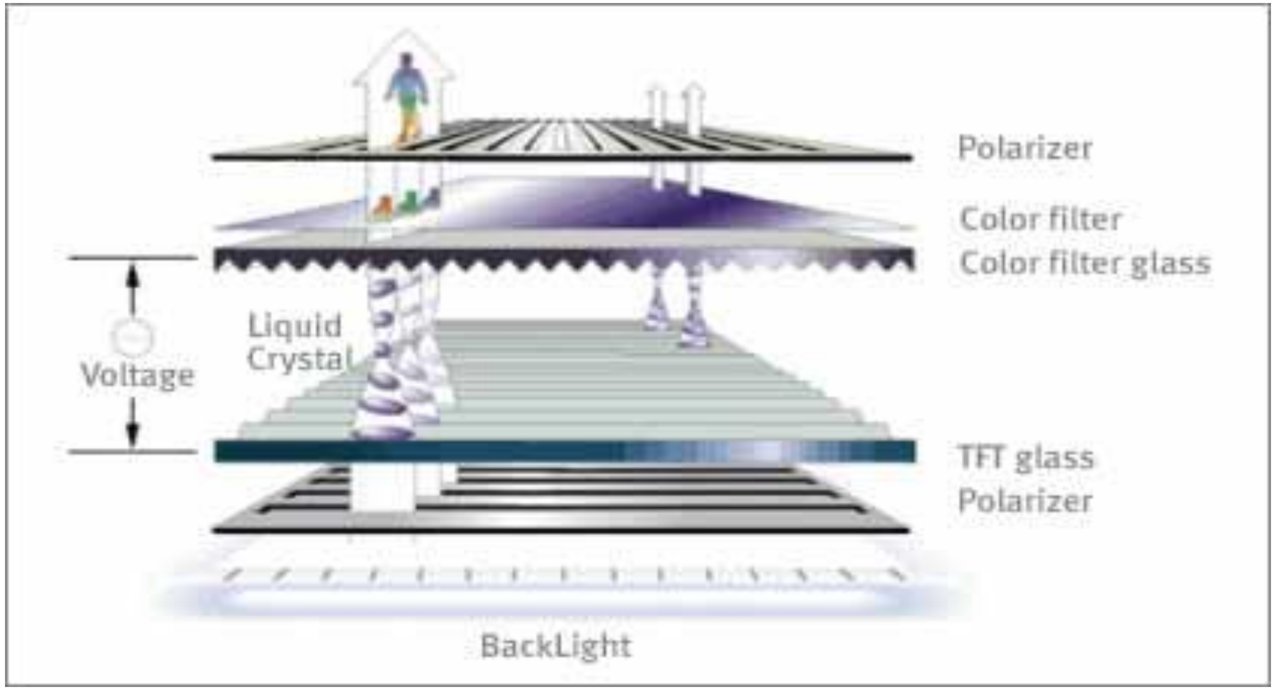


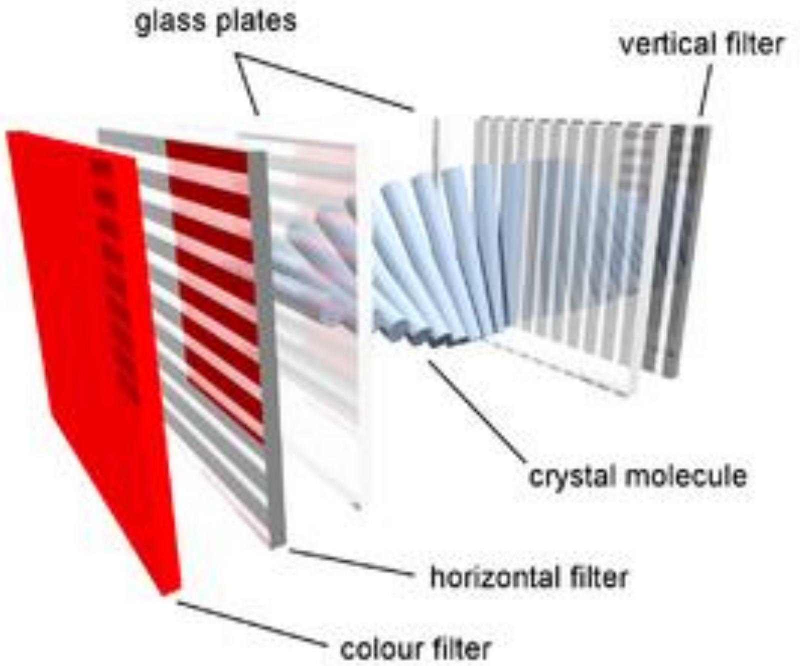
This is called a transmissive matrix-type display (also: light-valve)

LCD principle - a transmissive matrix-type display

- A layer of liquid crystals can change the polarization of light passing through it
  - Depends on voltage across the layer

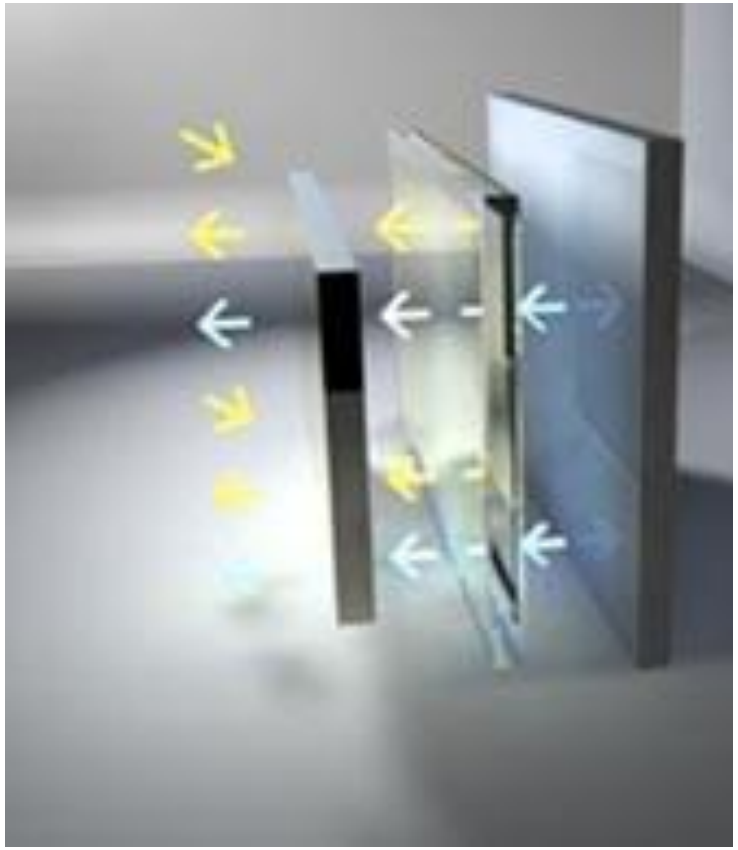
- When sandwiched between polarizing filters the amount of light from a backlight can be modulated



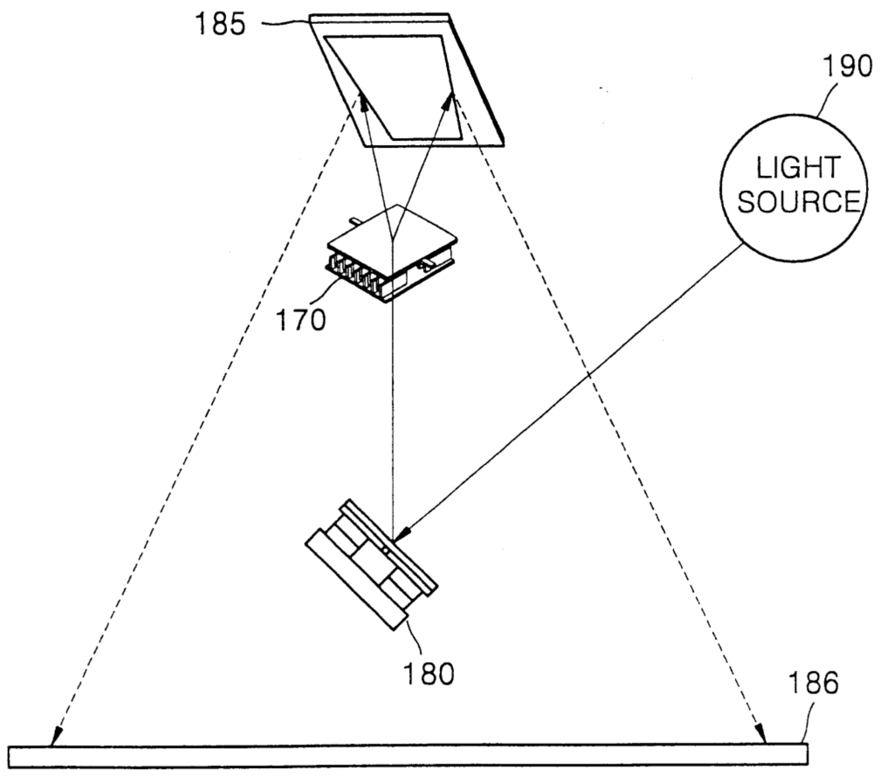


We can even imagine a display without a lamp

- Reflective matrix-type displays use the ambient light and a spatial modulator (light-valve panel)
- Using a half-transparent mirror AND a backlight, we get a transflective matrix-type display, e.g. used in mobile phones and cars



We do not need a matrix of lamps or modulators



2D Scanning with a single powerful modulated light source

Should be quick though to prevent flickering…

And we do not need 2D scanning either…

- 1D array with 9 LEDs rotating

Many physical phenomena to generate light

- Black-body radiation (Incandescent lamp)
- Photoluminescence (FL-lamp)
- Phosphorescence (glow-in-the-dark toys)
- Electroluminescence (LED, OLED, SS-laser)
- Many more…

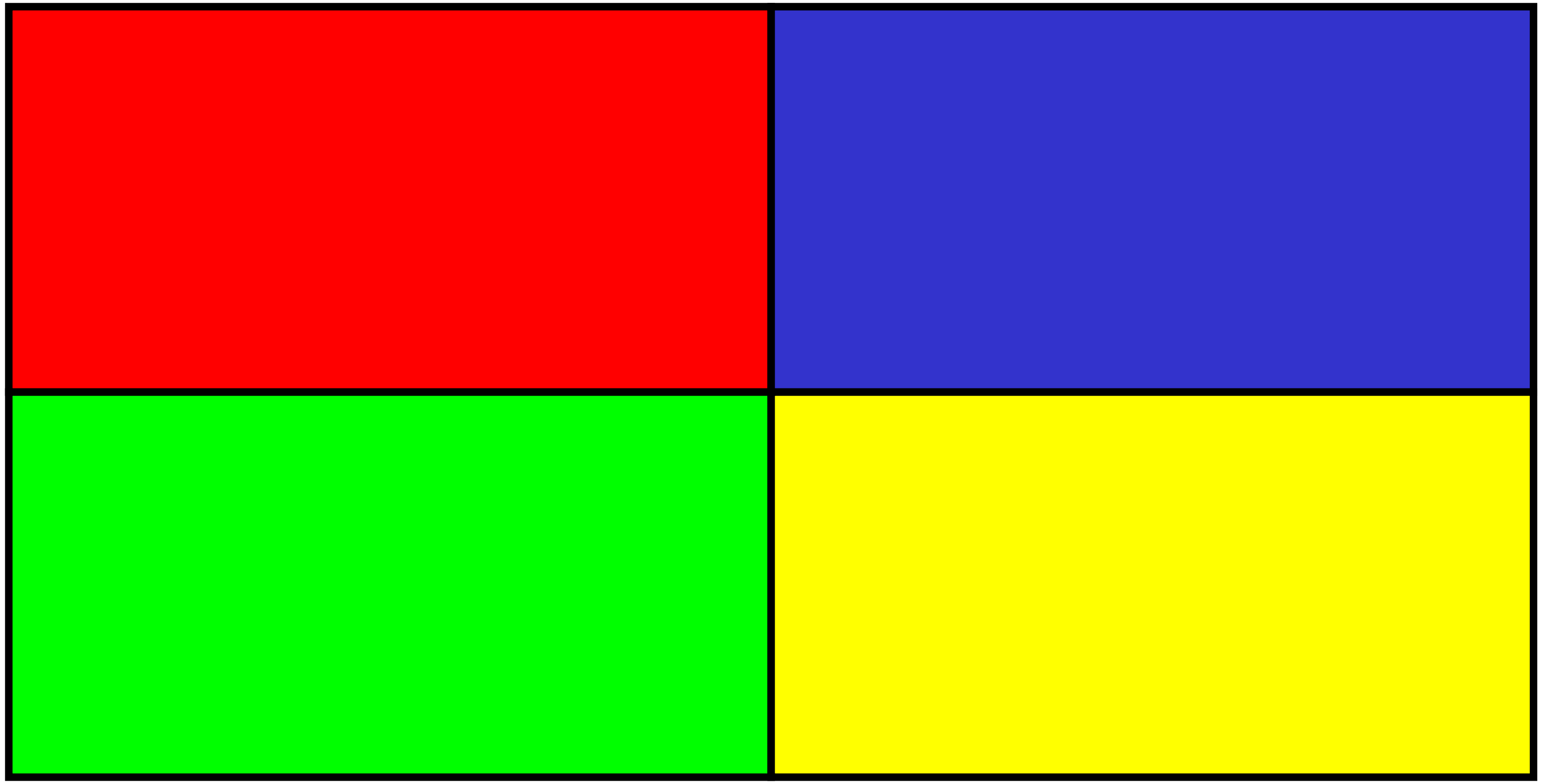
All applicable in matrix and scanning type of display

….

But how do we make adjustable color?

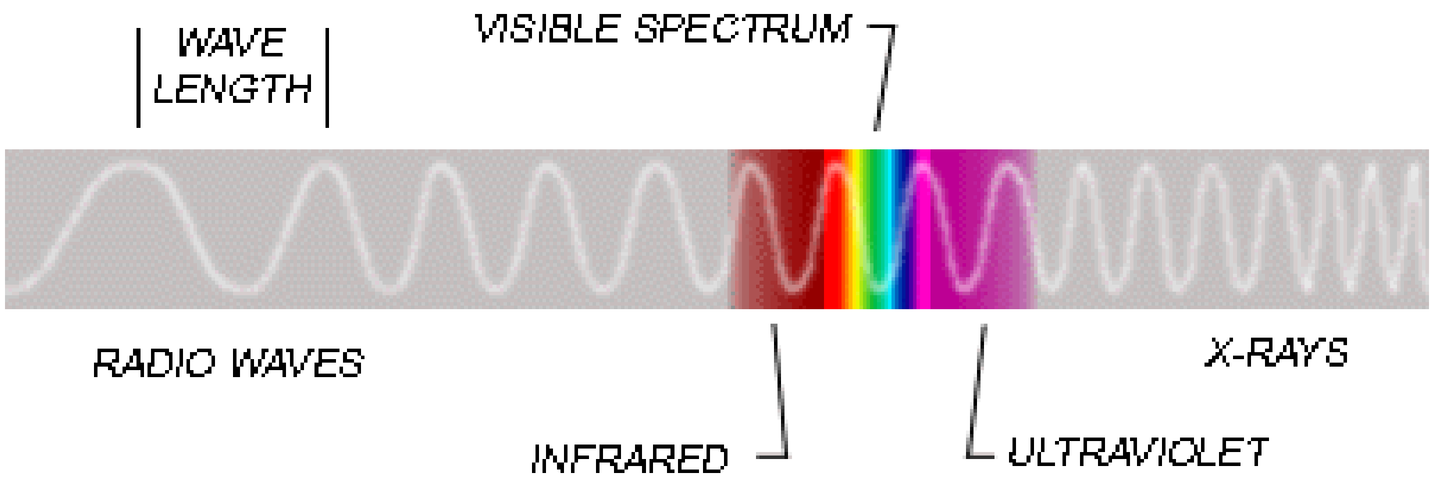
Color definition

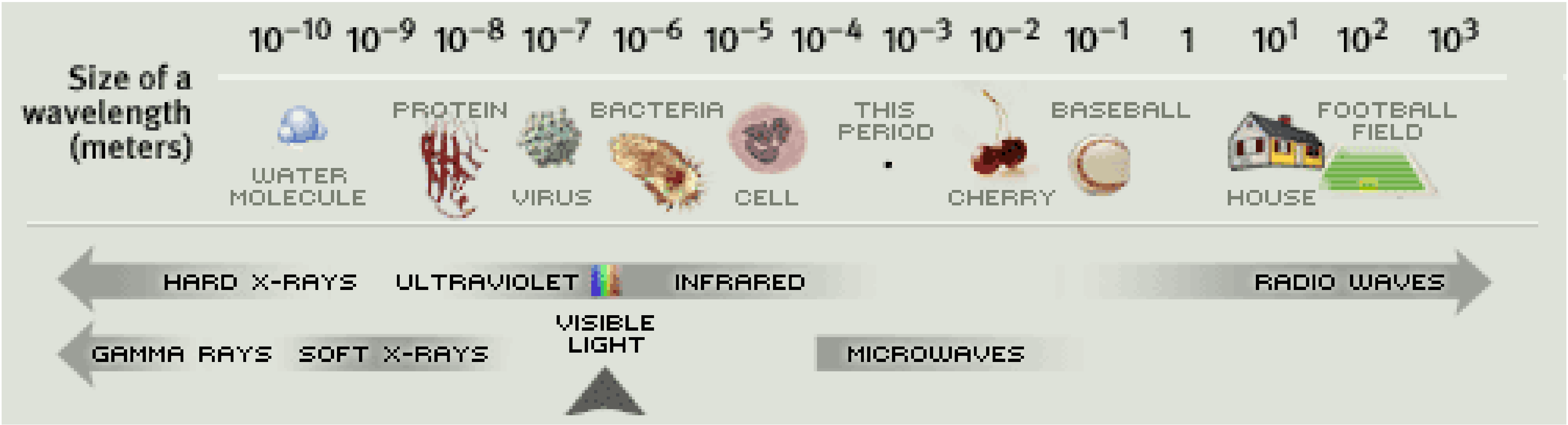
- Color is that aspect of visual perception that allows us to distinguish differences between two fields of view caused by differences in the spectral composition of the radiant energy emitted by these fields of view



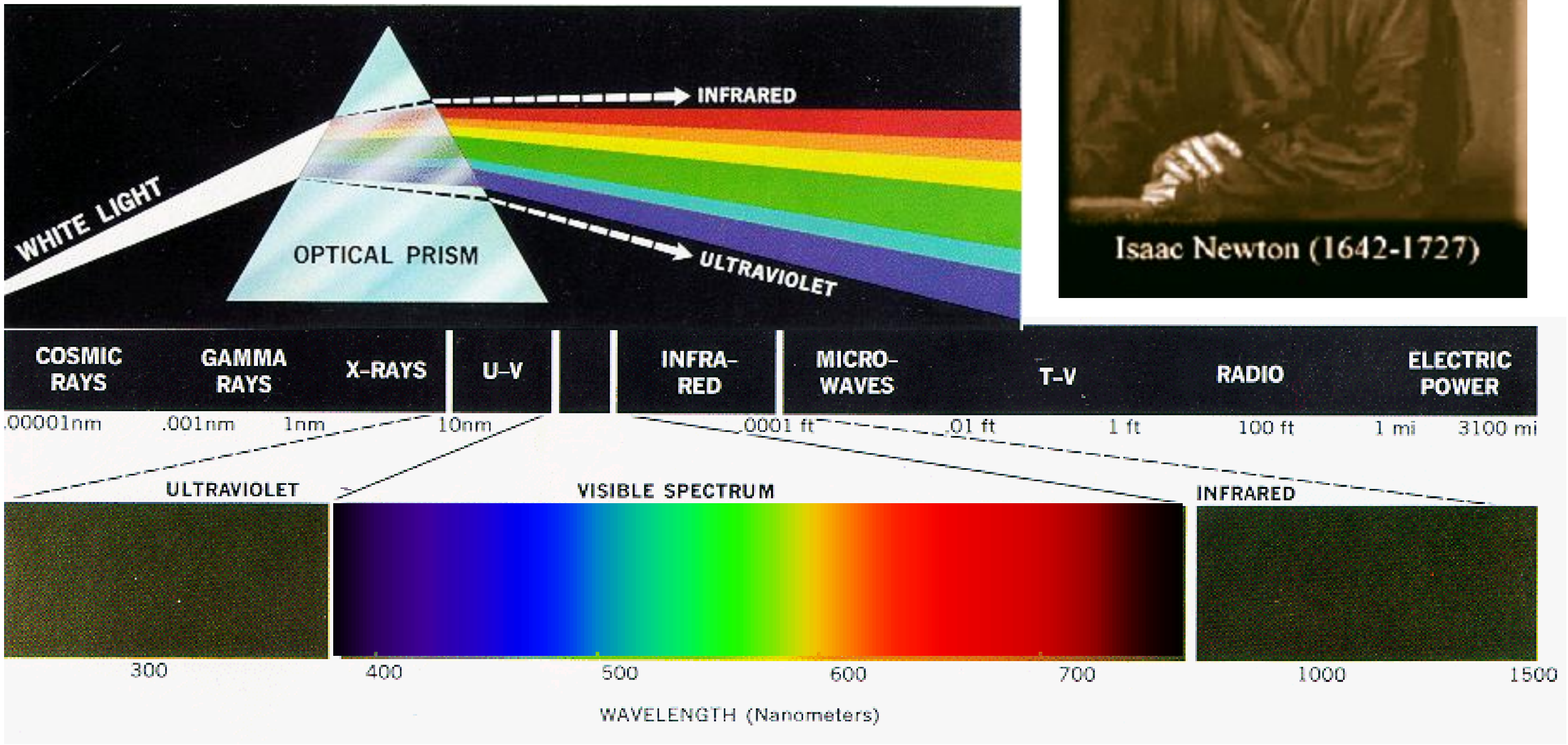
Only part of the spectrum is visible

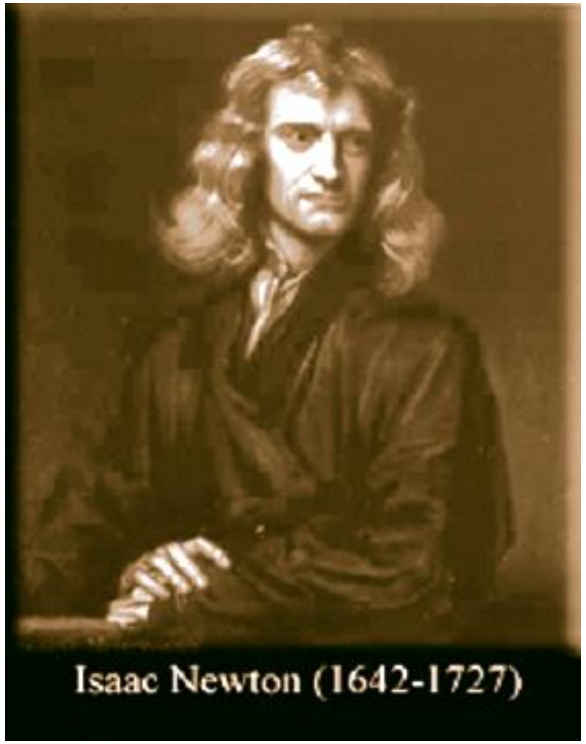
TU/e





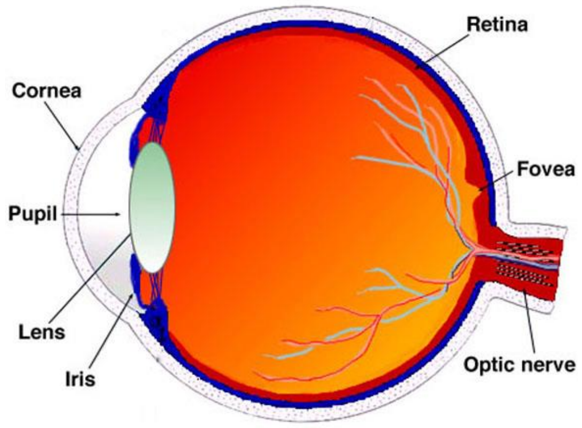
Relation wavelength and colour

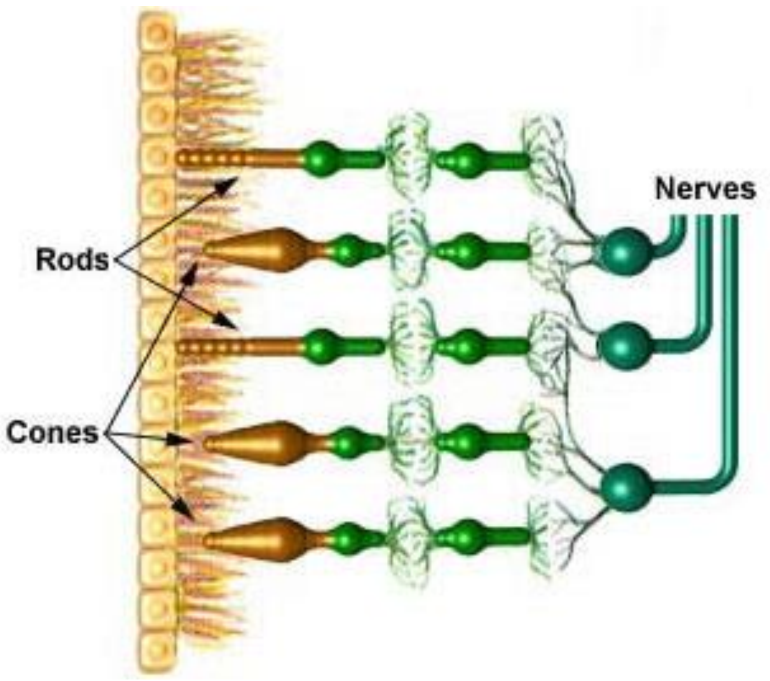


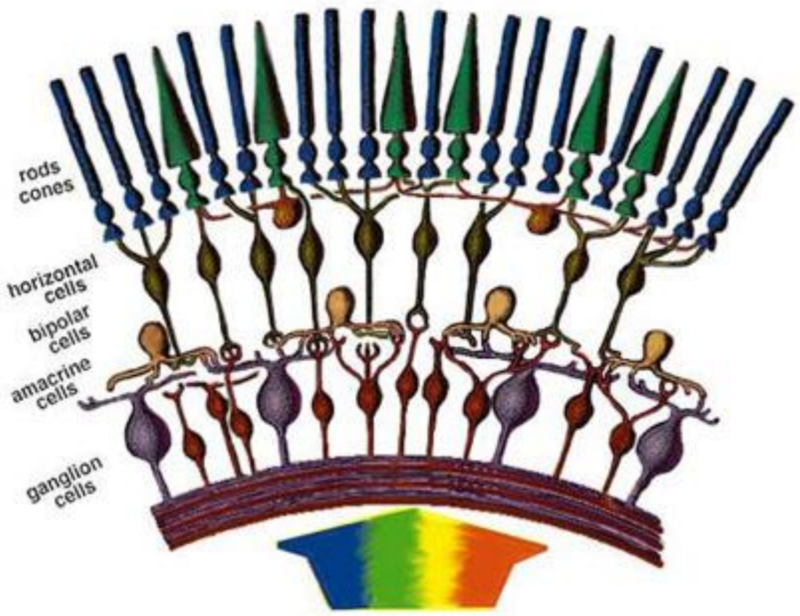


The human eye

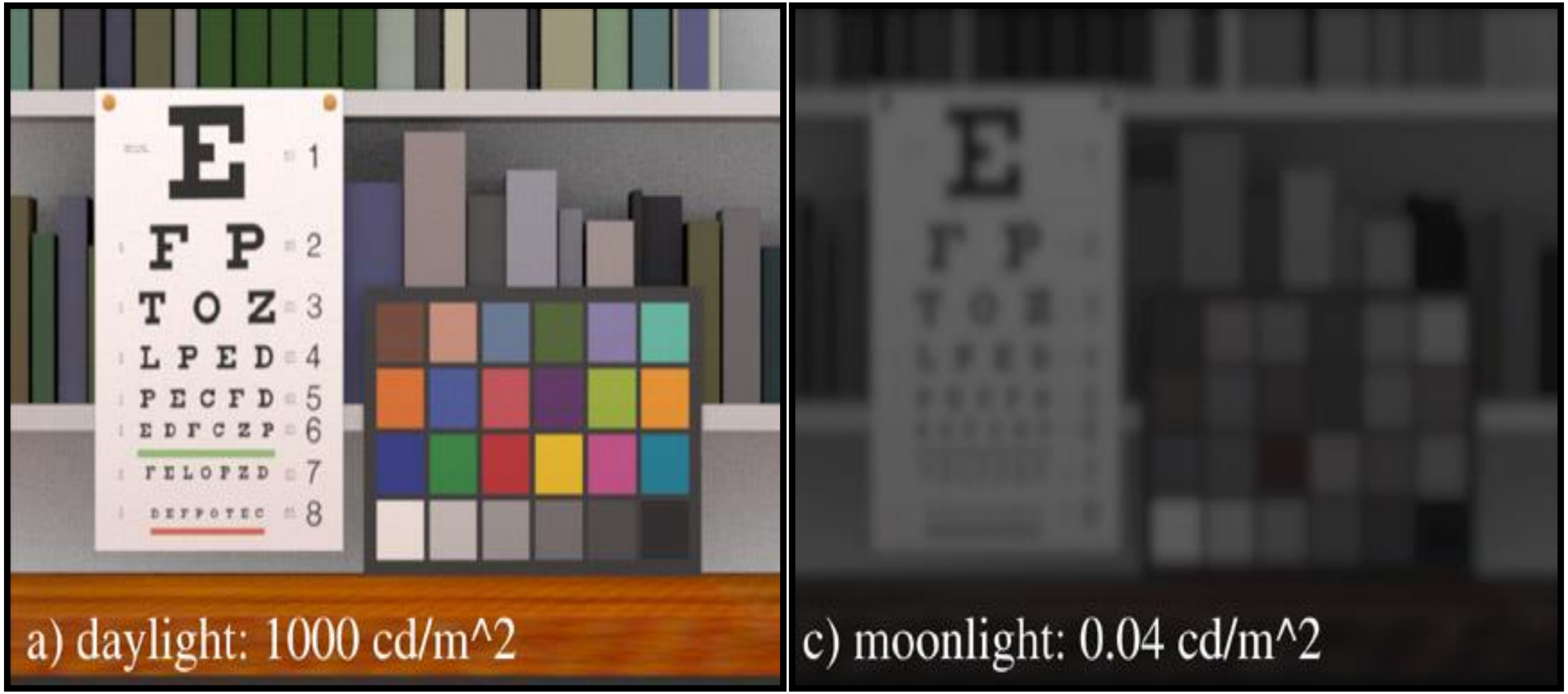
- the retina has two type of receptors, rods and cones
- we perceive color only with the cones, at higher brightness levels
- rods and cones are at the back of the retina, the nerves are at front



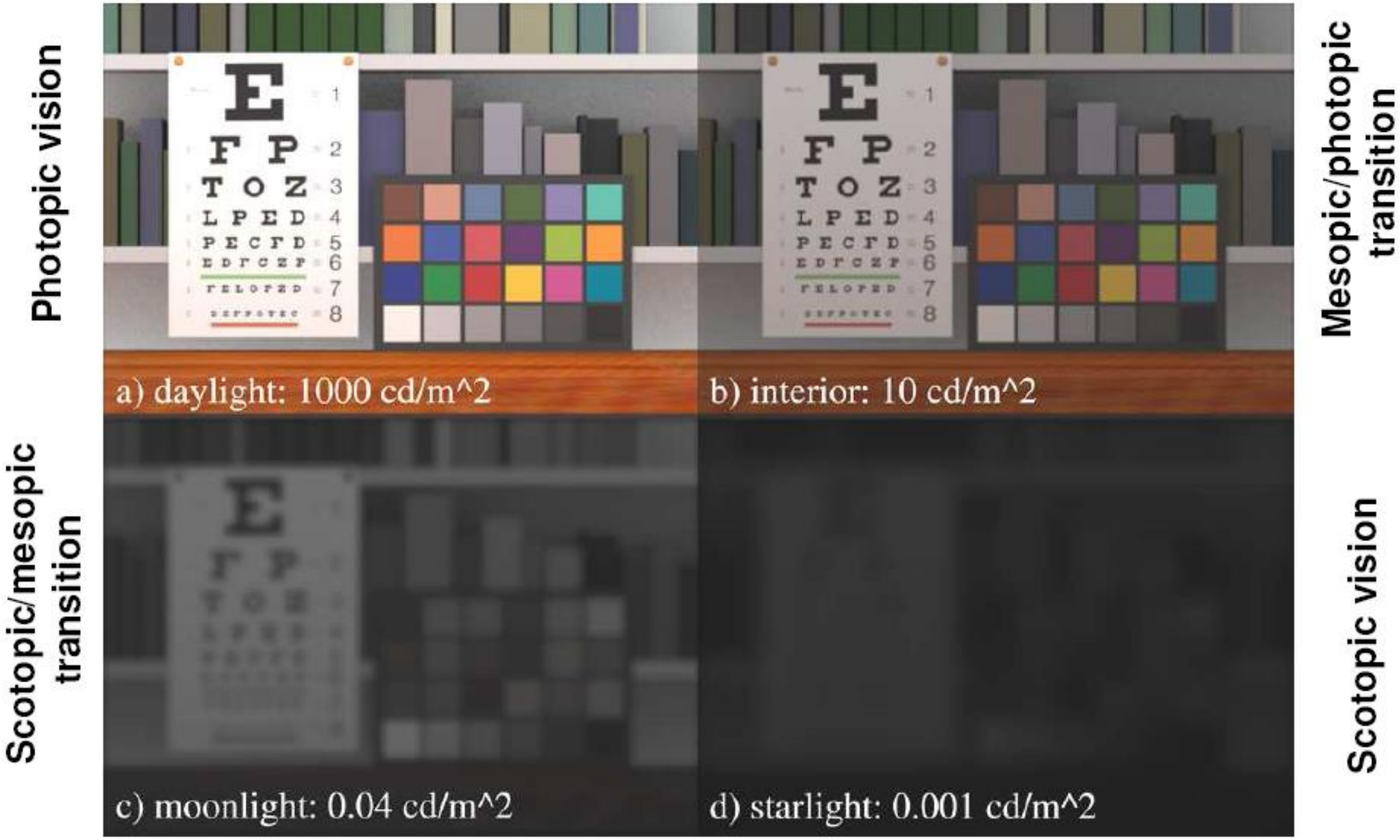




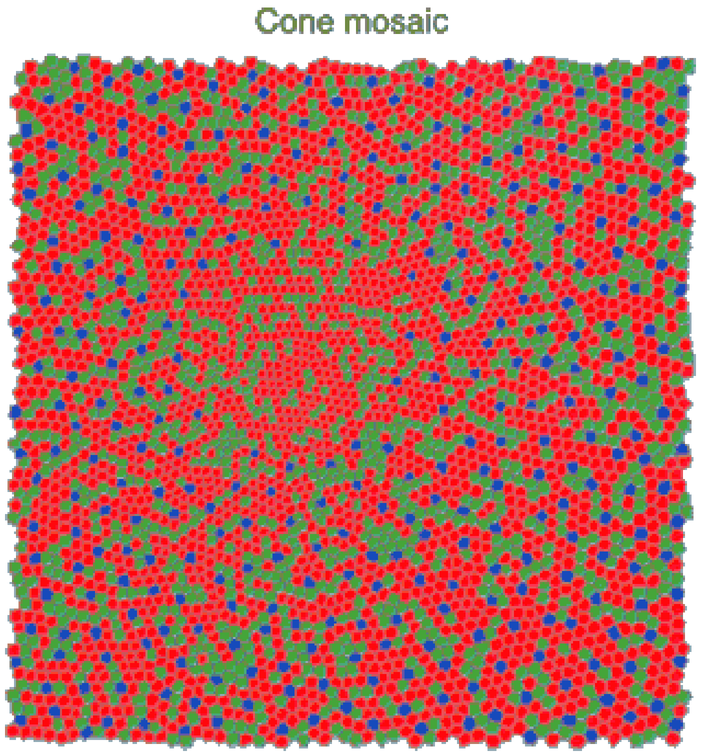
Cones and rod vision (Ferwerda et al, 1996)



It is a continuum…, and also resolution changes

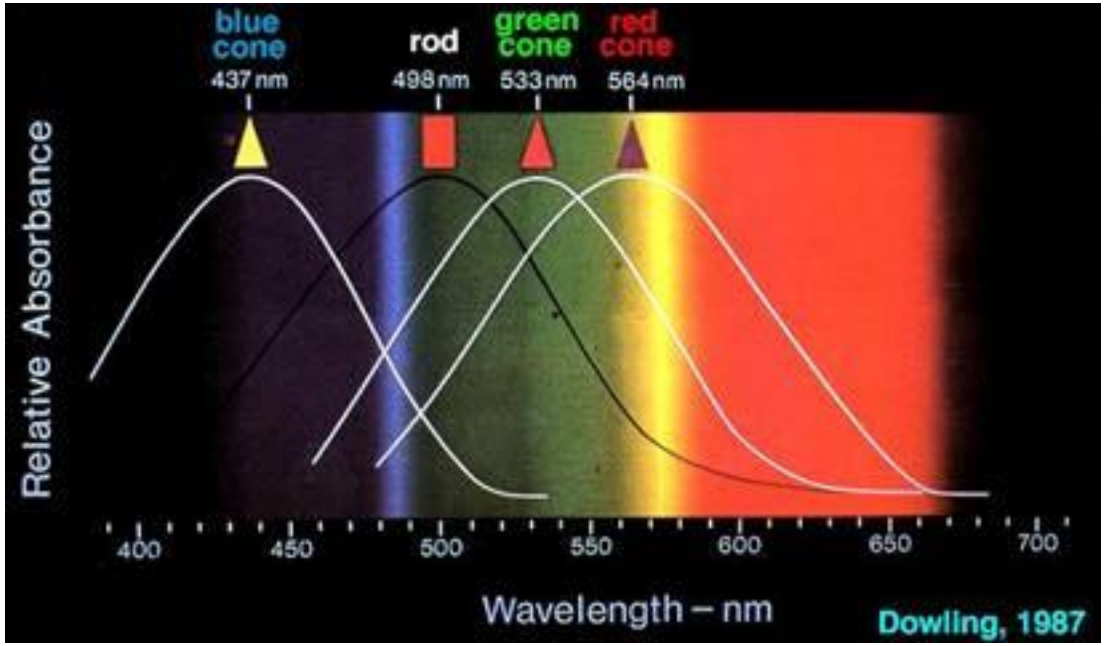


The human eye, perception of colour



Three types of cones:
L (63%), M (32%) and S (5%)

S M L

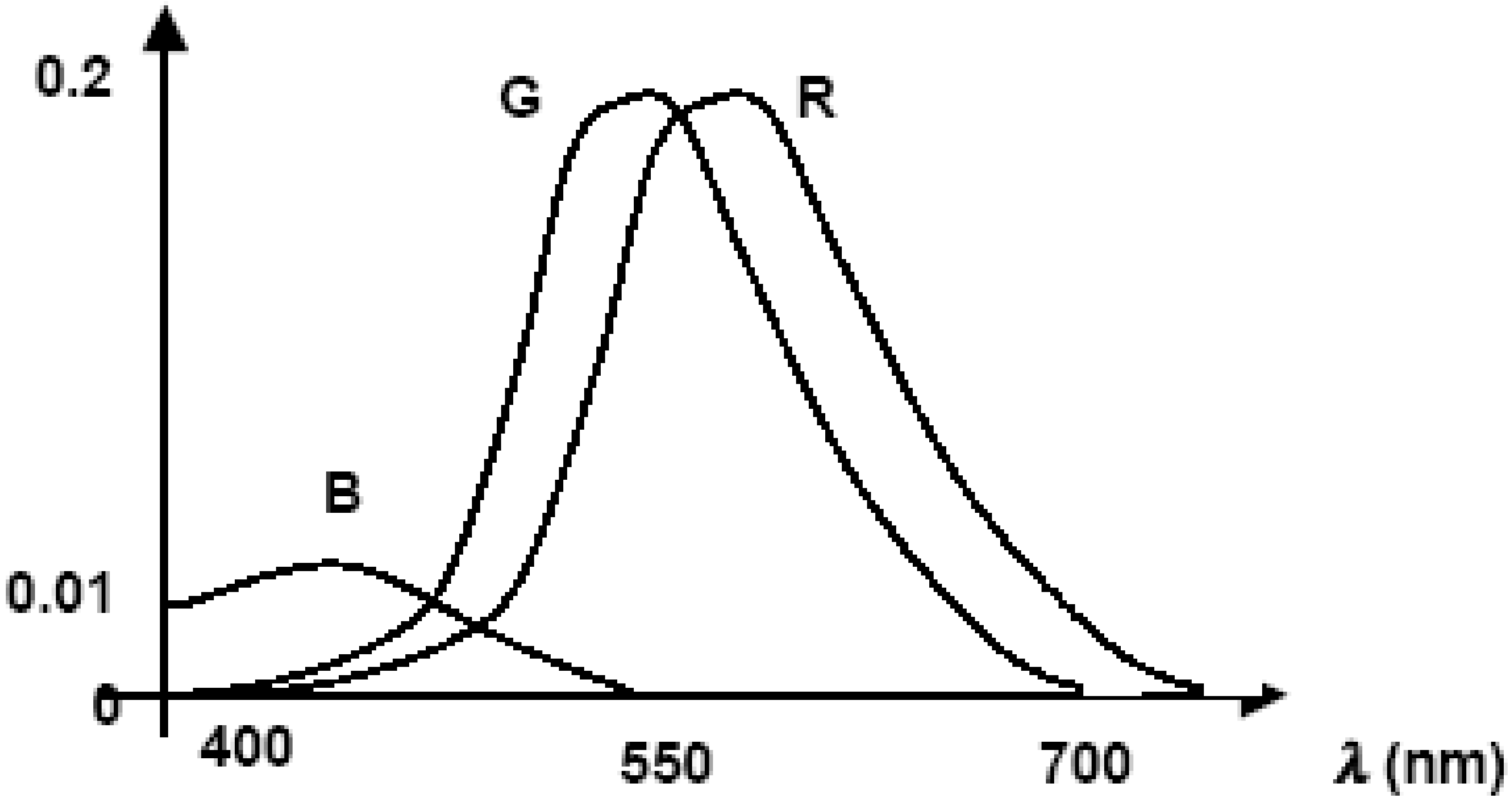


Spectral sensitivity of
rods and cones

We perceive the same colour whenever the different types of cones are stimulated in the same ratio. The spectrum can then be different!

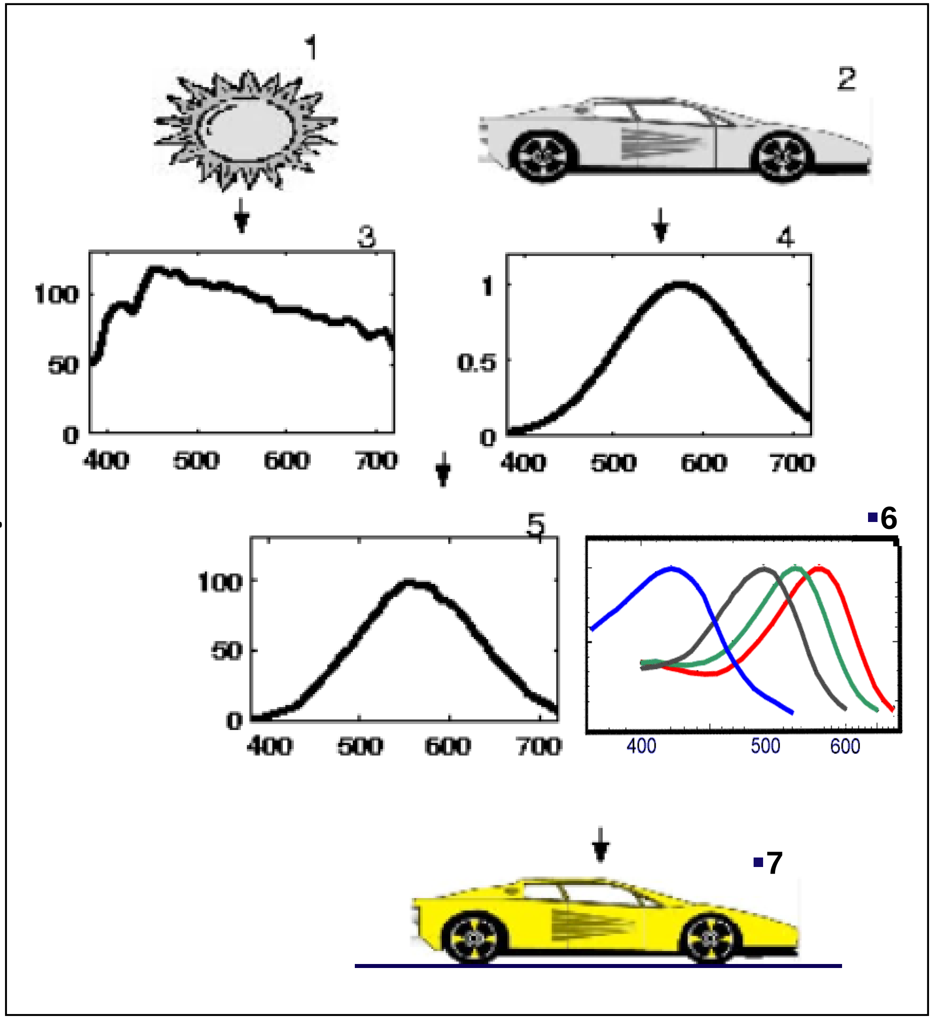
Relative response of the 3 types of cones

The eye’s response to blue much weaker than to red and green



Color vision

- Illumination, e.g. by sunlight
- Reflection by object
- Spectrum of daylight
- Convolution of daylight with colored object and…
- Color sensitivity of cones…
- Gives perceived color



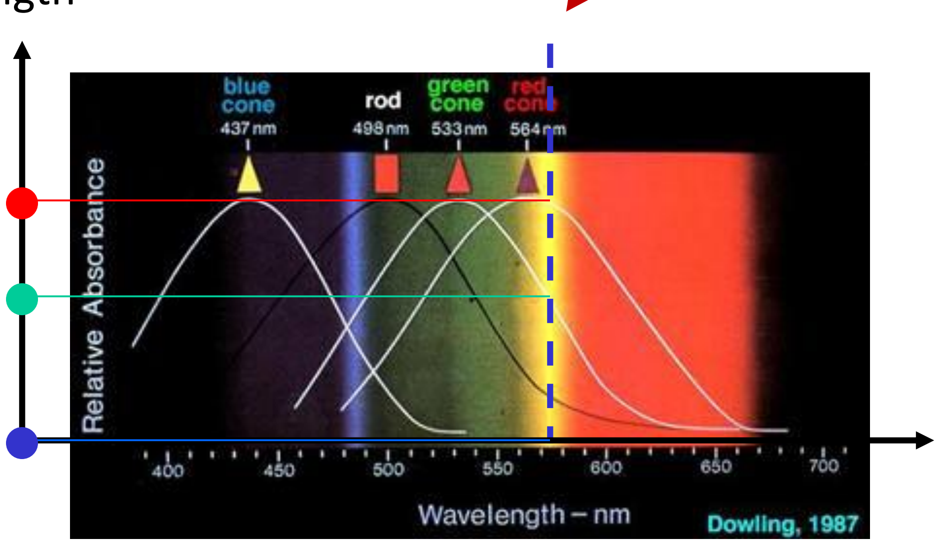
Color vision

- The perceived color is determined by the number of photons on each of the three types of cones
- Cones are photon-counters with build in spectral filter
- Specific spectral distribution already lost at retina
- Two different spectral distributions may appear as the same color under a given illuminant
- Species with more (birds, retiles) or less (most mammals) primaries exist

To see yellow, no wavelength of 575nm is necessary

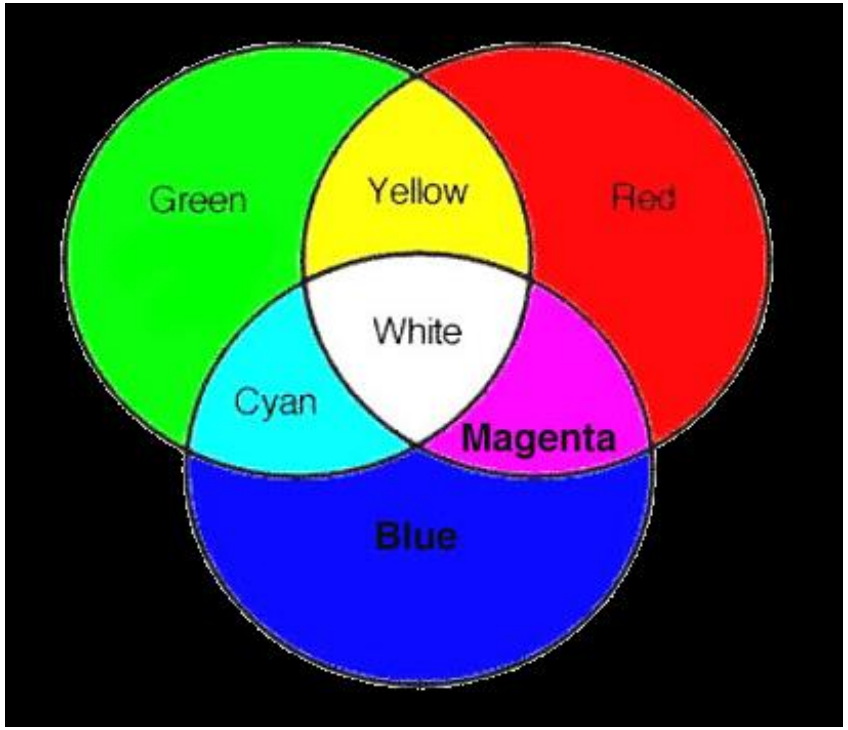
strength

Ratio of red, green and blue determines perceived colour



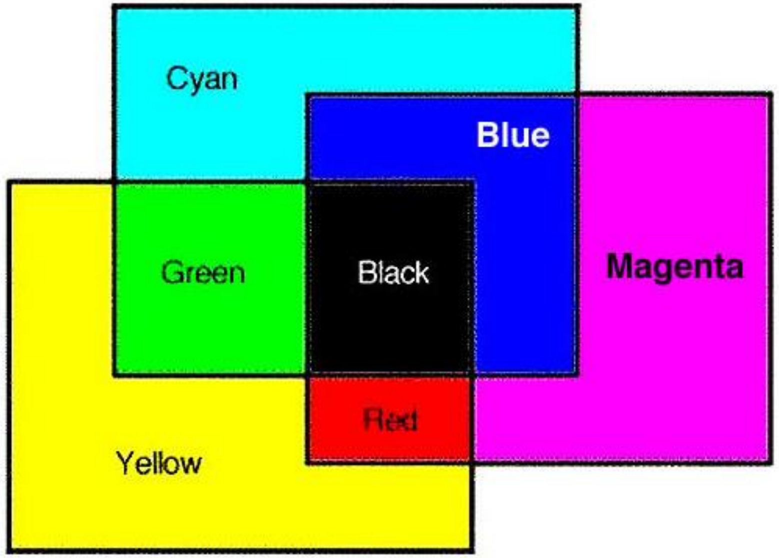
The same colour perception is caused by a mix of light with 650nm and 530nm and no 440nm

Additive colour mixing



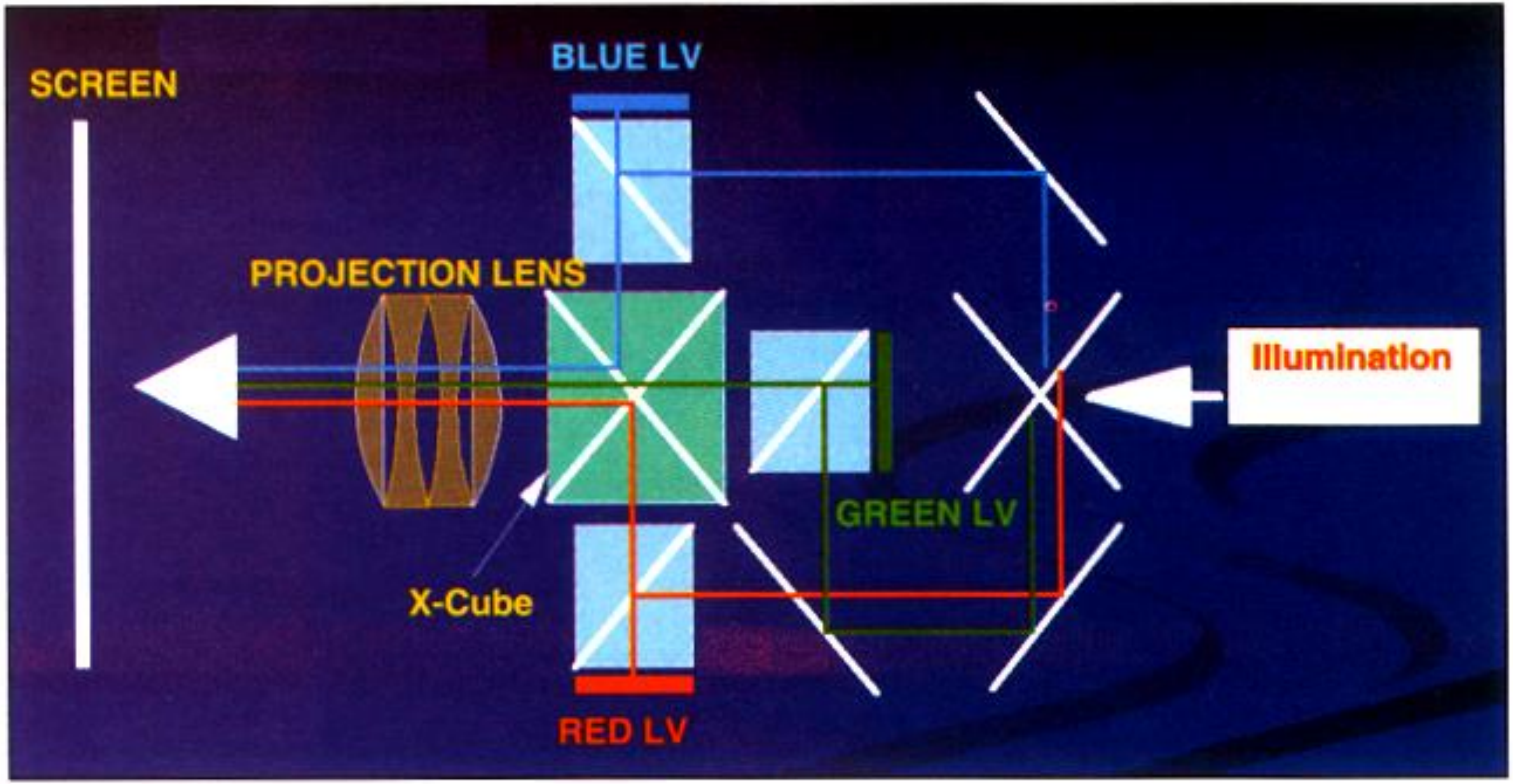
- Used in displays and in fluorescent lamps
- Based on red, green and blue primary = RGB-model, sometimes white added for improved efficiency (RGBY)
- Primaries defined by emission of phosphors or LEDs (lamps, CRT, PDP, OLED), or color filters (LCD)
- Only 3 primary colors required to create every color sensation

Subtractive colour mixing

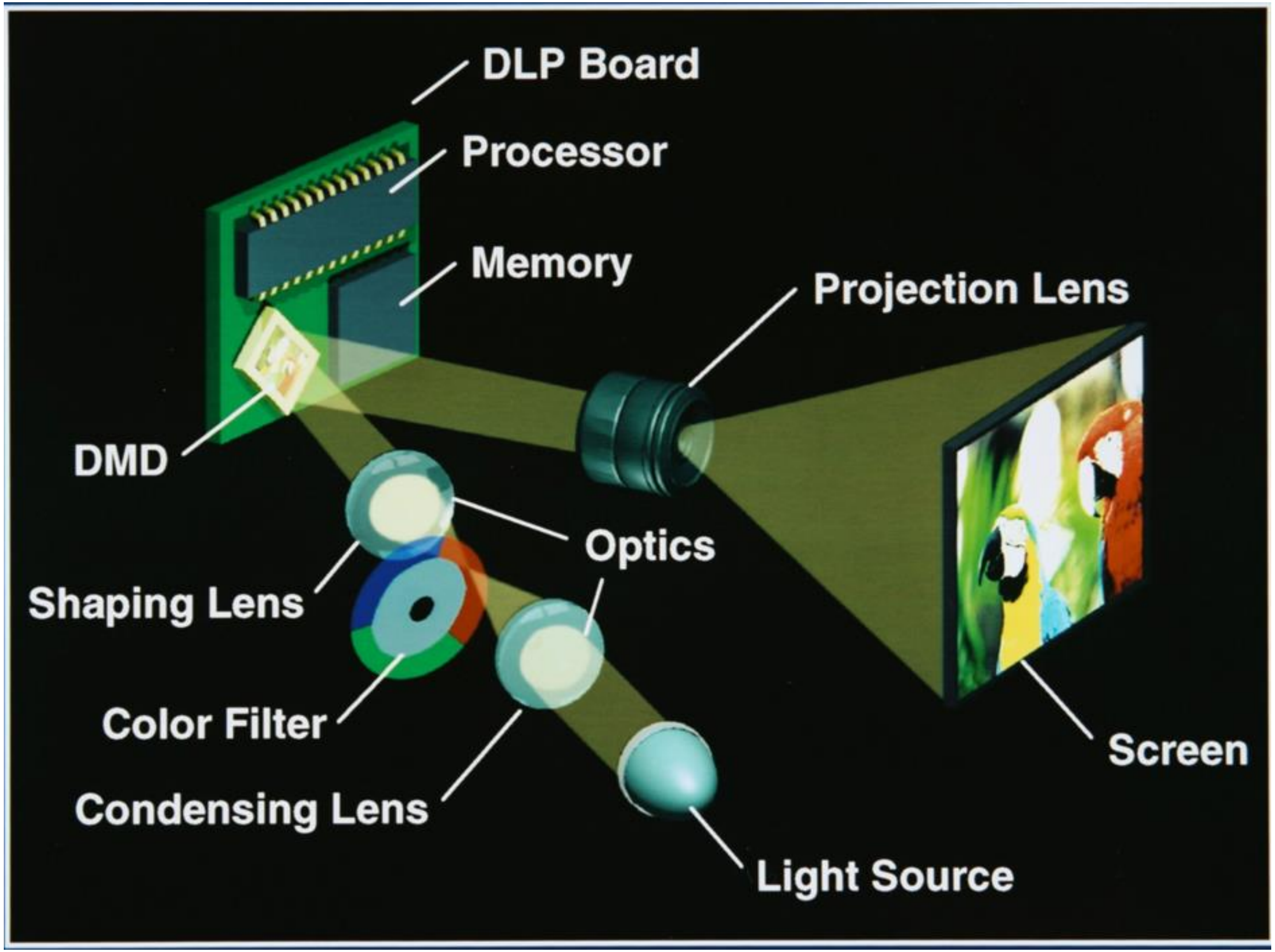


- Used in printing and photography
- Based on cyan, magenta and yellow primary = CMY-model
- Sometimes black primary added because combination of C, M and Y often results in dark brown instead of black = CMYK-model

Color synthesis – Optical superposition (projection)

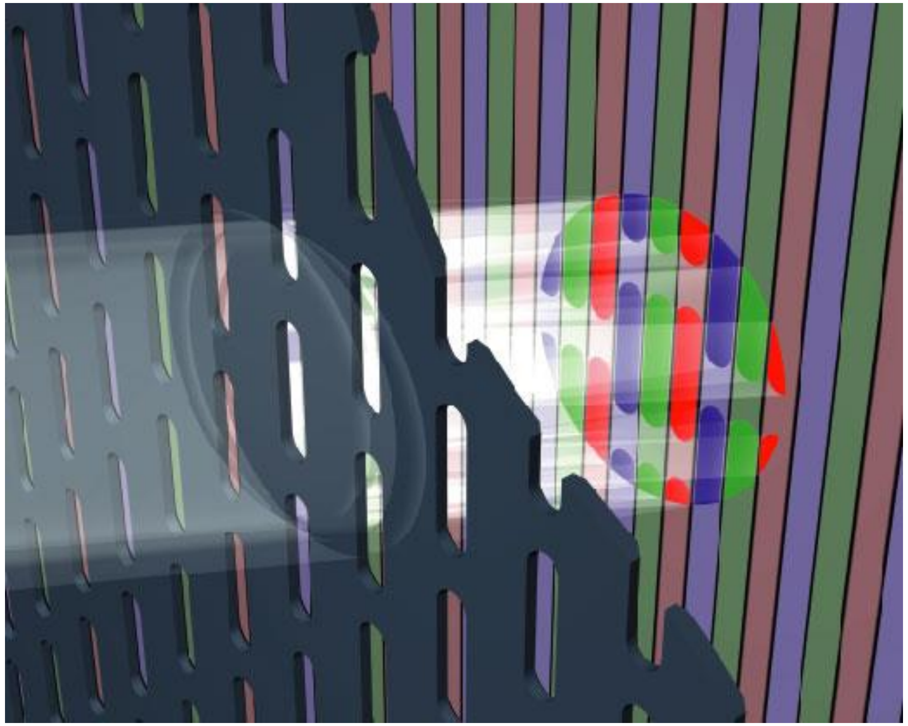


Color synthesis – temporal synthesis (color sequential)

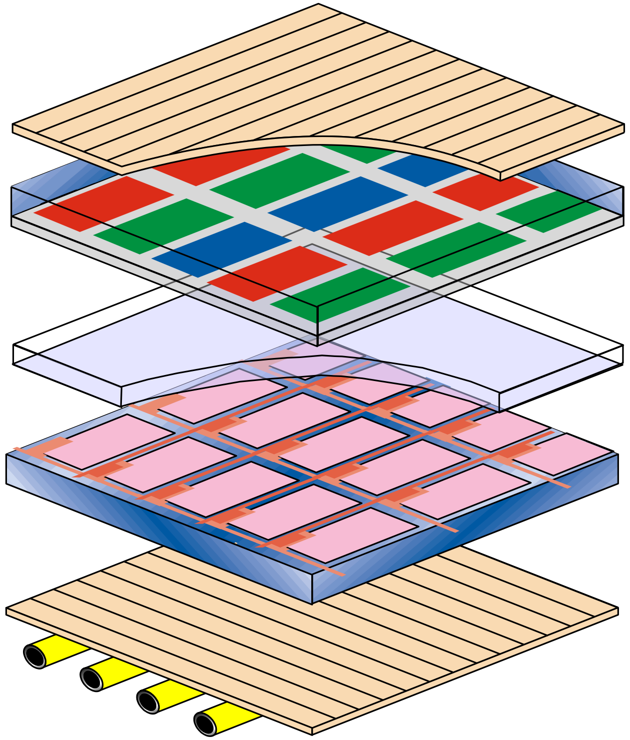


Color synthesis – spatial synthesis (CRT, LCD, PDP)

Shadow-mask (colour CRT)

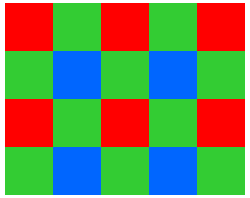


Matrix display panel

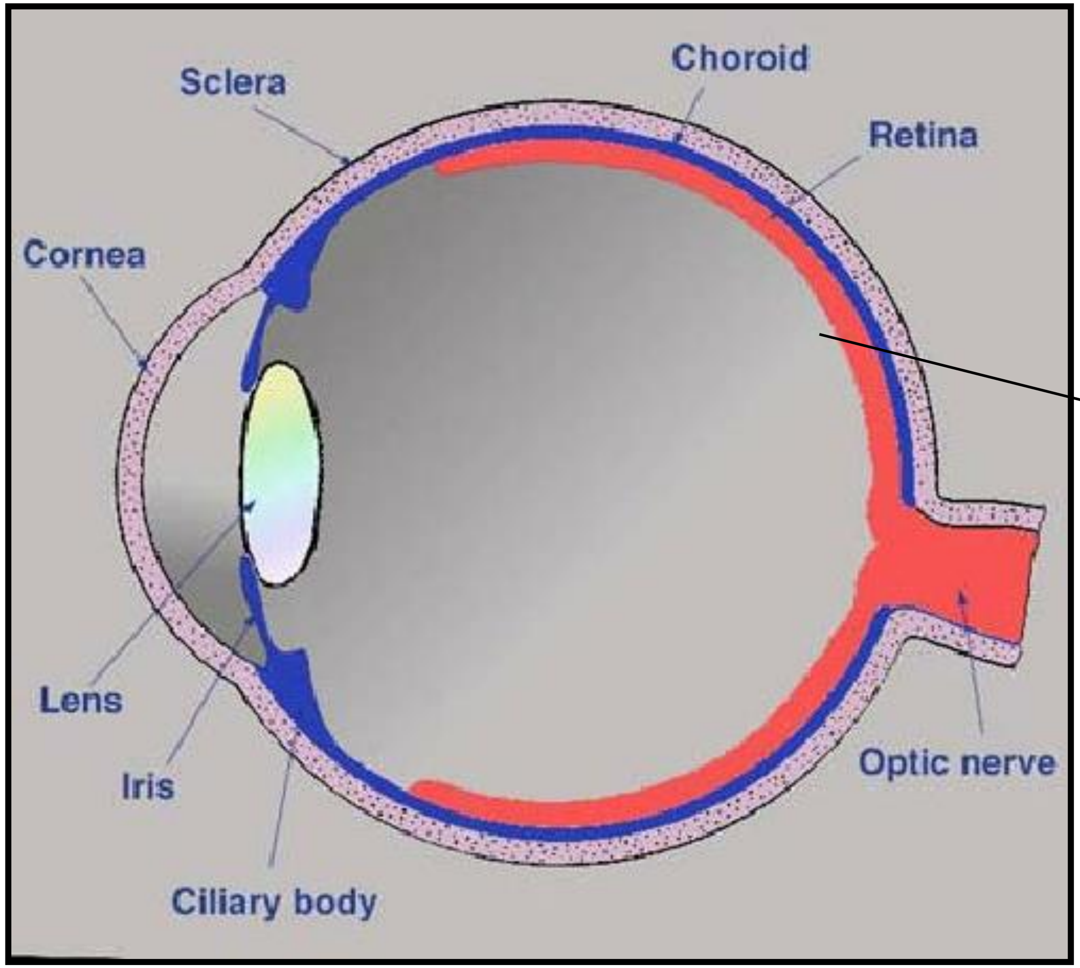


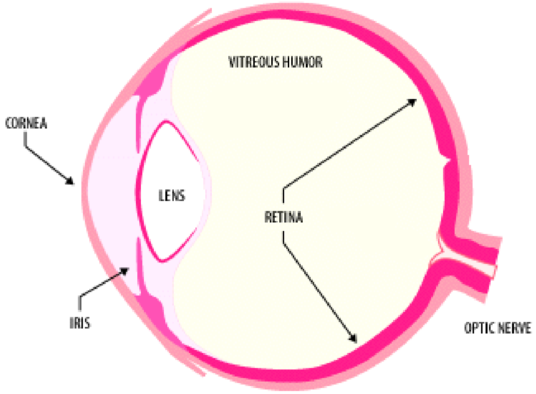
The same can be used at the camera side

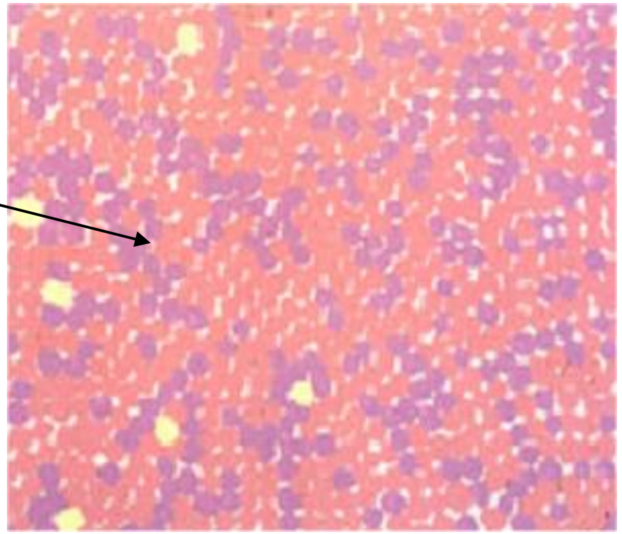
- Superposition in the high-end camera:
  - Split the light from the lens with a prism and…
  - Use separate (CCD-) sensors for the red, green and blue image
- Colour sequential used in slide scanners
  - Scan the slide with red, green and blue light (filters) successively
- Spatial synthesis in economy cameras (home-video)
  - Deposit colour filters on individual cells of a (CCD-) imaging device (Bayer pattern)



The human eye – resolution (how many pixels?)







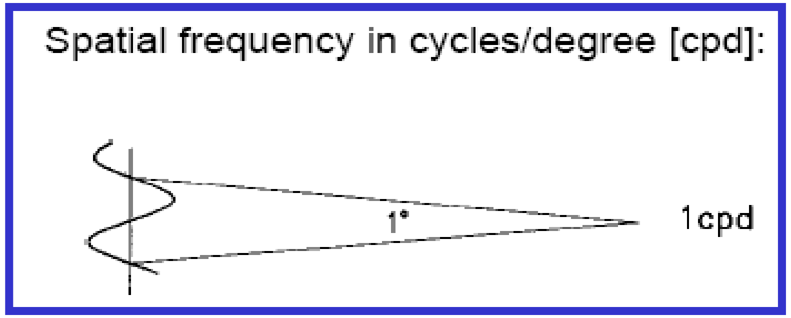
The image is spatially sampled by the retina!

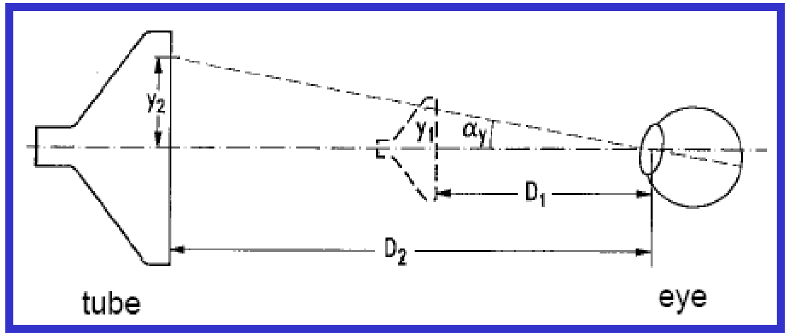
Resolution not constant over field of vision

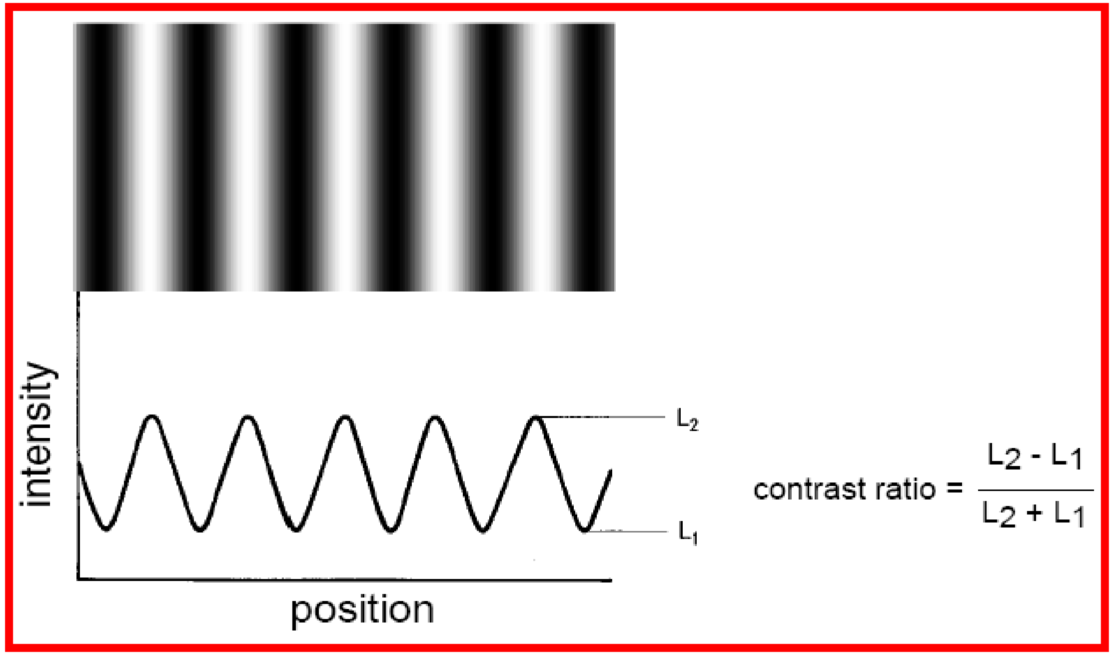
Measuring the limits of vision

TU/e

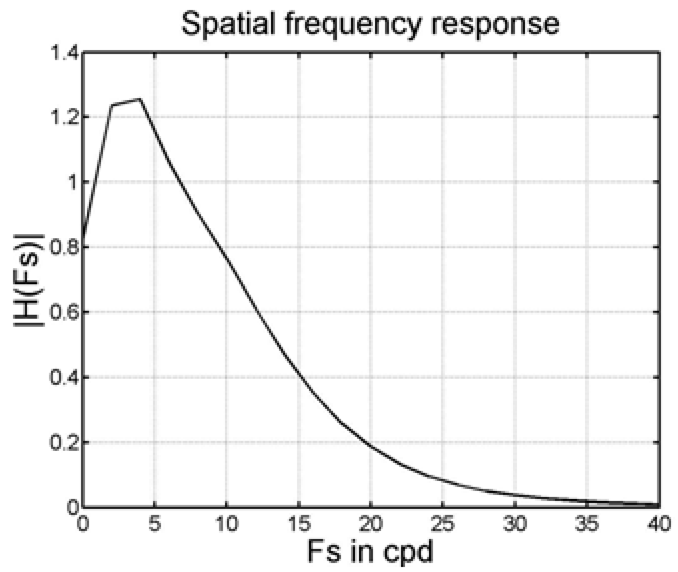
- “Contrast grating” used to analyze contrast sensitivity . Can vary:
  - Spatial frequency (bar spacing) - cycles per deg (c/deg)
  - Contrast (amplitude)
  - Orientation

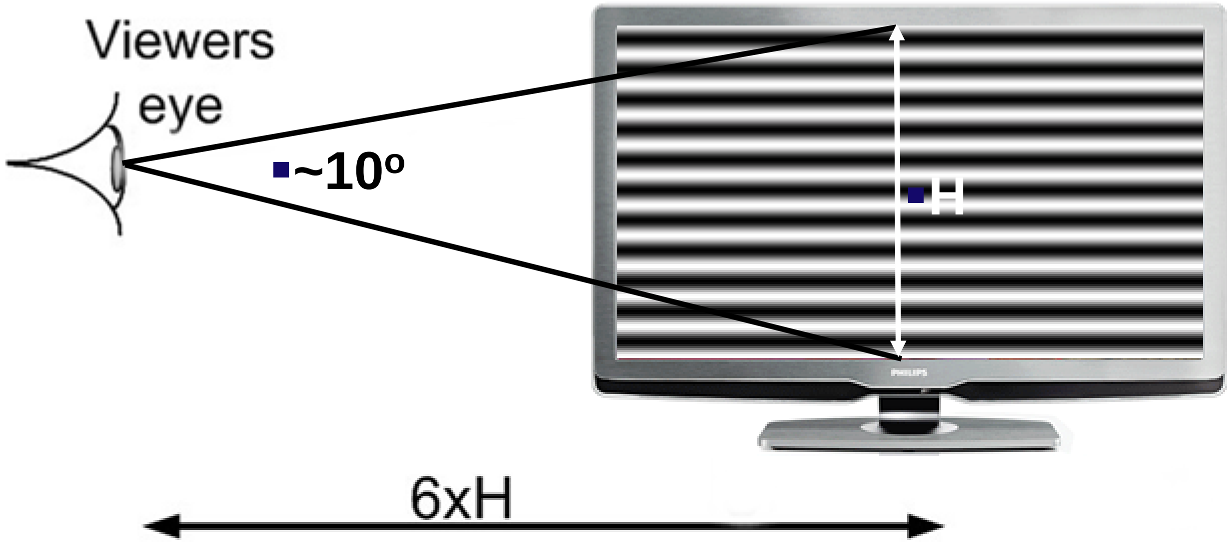






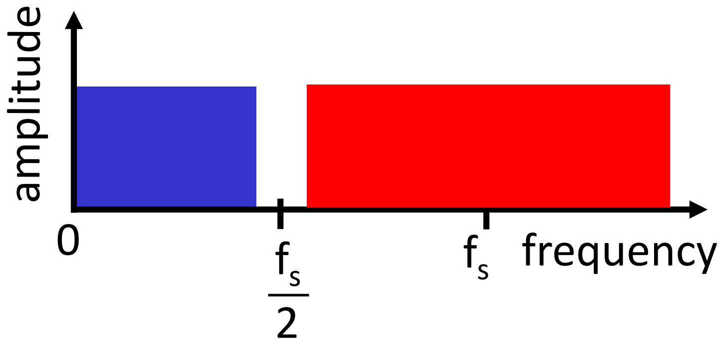
What is the required sampling grid? (V-dimension)

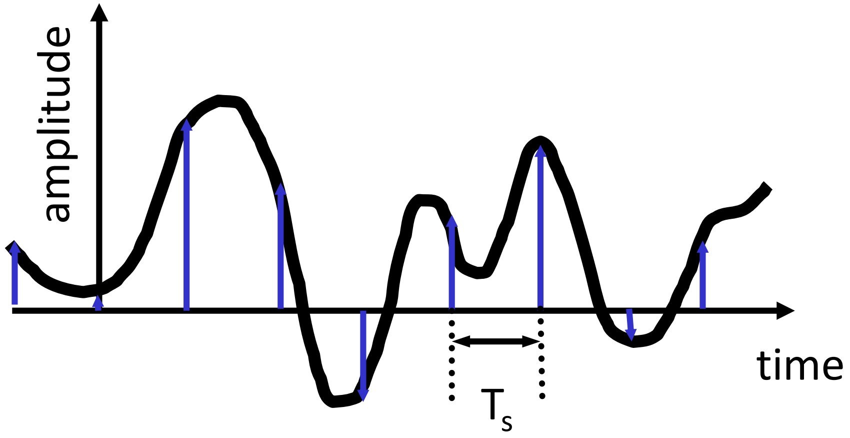




- We can resolve about 30 cycles/degree
- At 6 times picture height, viewing angle is about 10 degrees
- The finest pattern on the screen is 10*30=300 cycles
- Sampling theorem: we need at least 600 samples (lines)
- Is this conclusion correct?
  - What is the sampling theorem?

The sampling theorem





We have a continuous signal

We sample it to obtain a discrete representation

Sampling theorem: we can reconstruct the continuous signal from its discrete representation, provided it contained no frequencies above half the sampling frequency

How many (brightness) levels required for digital processing?

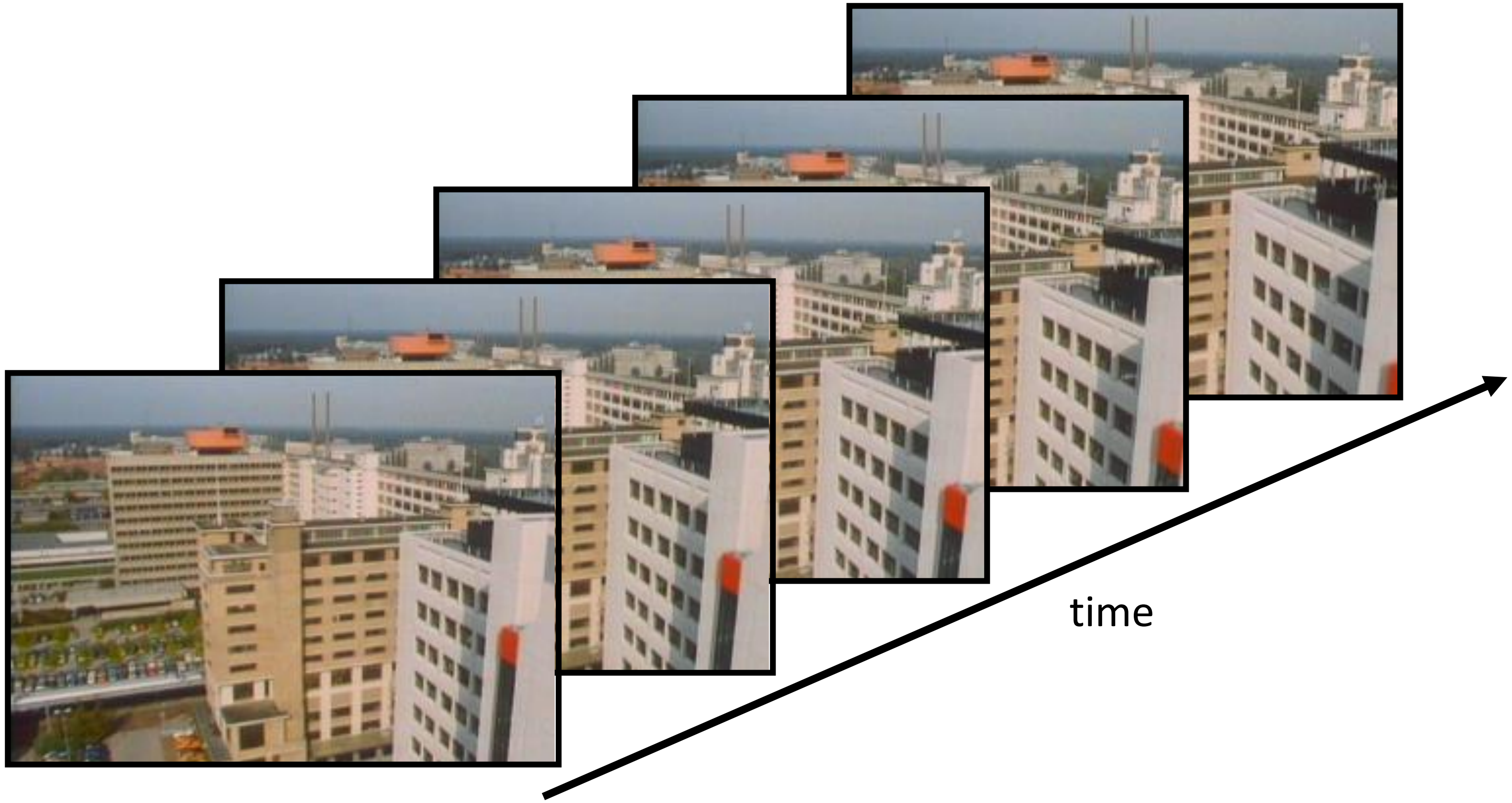
Experiments: we can distinguish about 200 levels in an image

We shall use 8 bit representation of luminance

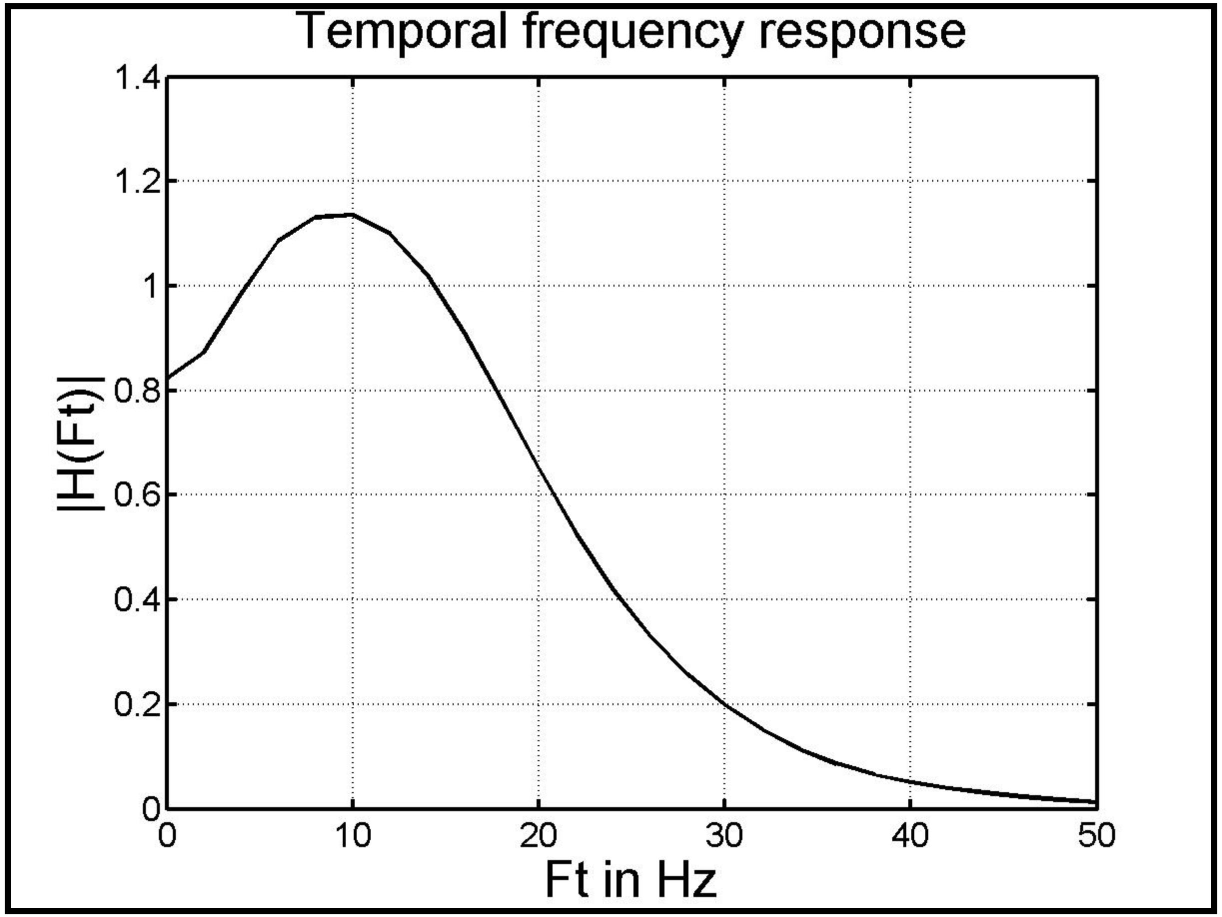
Video is time discrete in the temporal domain

More pictures/second affects:

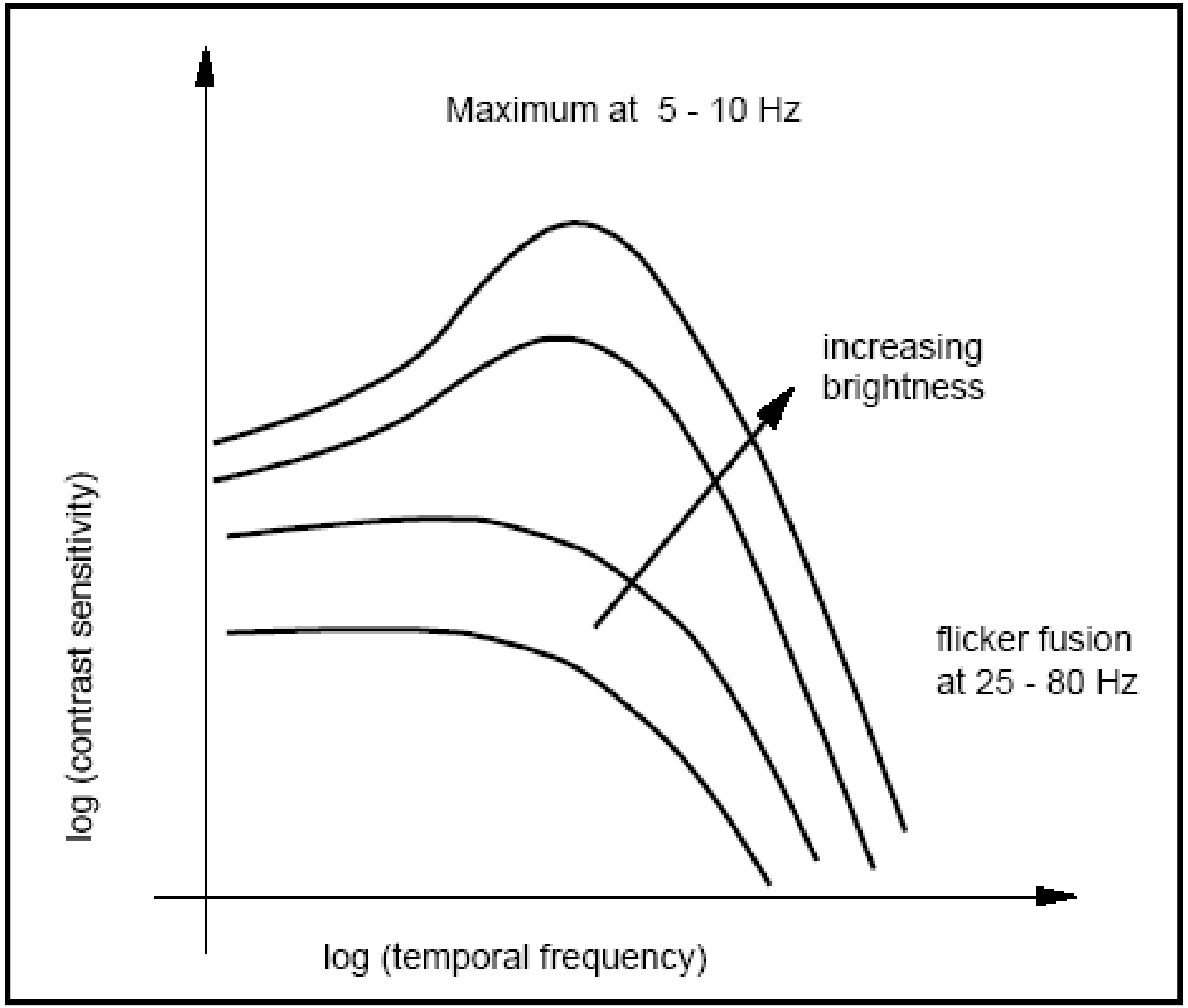
- Motion portrayal
- Flicker



Frequency response in the temporal domain



Depends on the brightness level, and viewing angle



- The flicker threshold shifts to higher frequencies in the periphery of the vision field
  - Allows us to rapidly recognize approaching danger

Consequences for the design of a video system

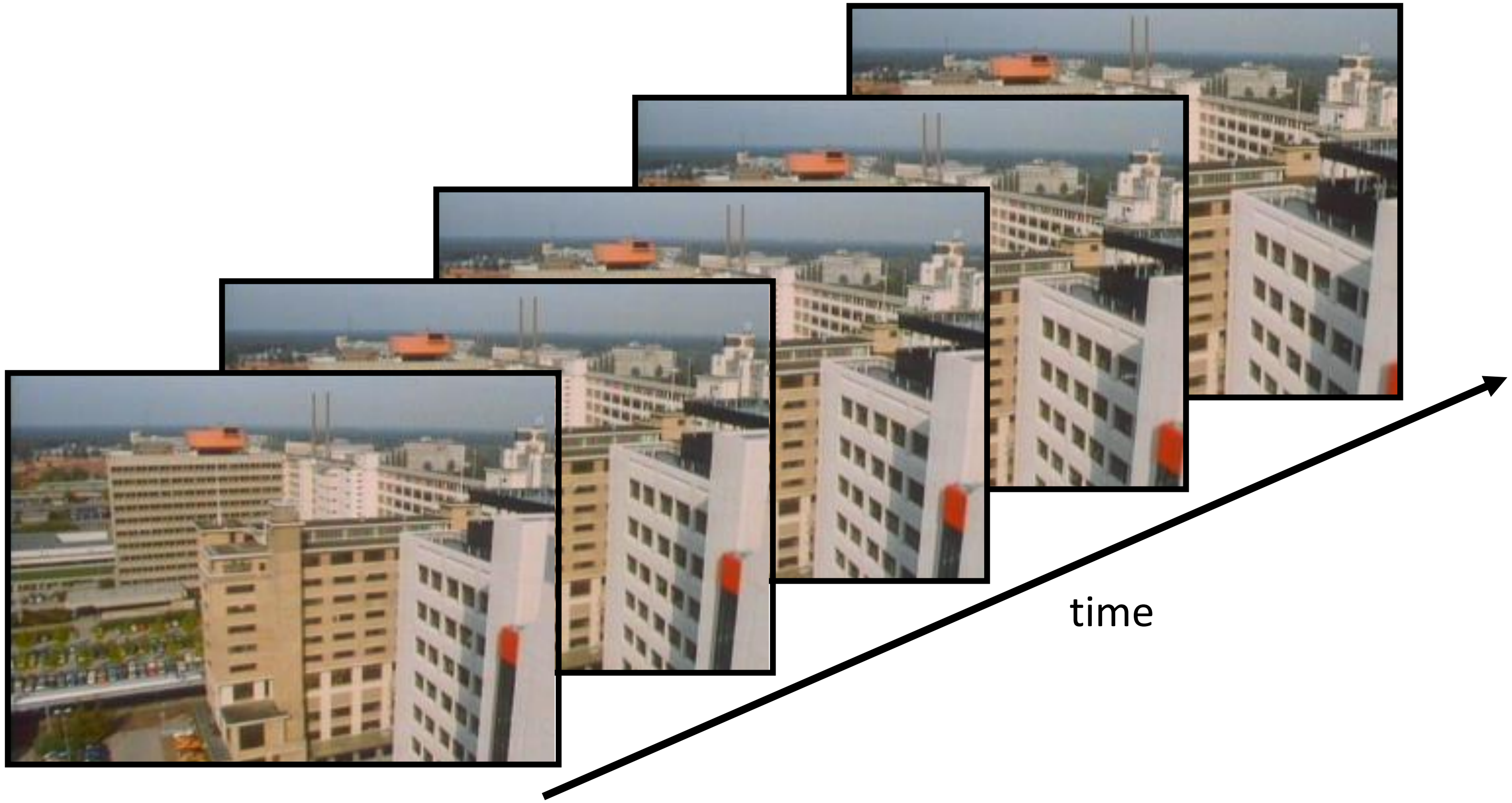
- The upper limit of the temporal contrast sensitivity curve determines how many pictures/second we need
  - To prevent visible flicker
  - For motion portrayal a lower threshold

- TV needs less pictures/second than a PC-monitor
  - Because of smaller viewing angle

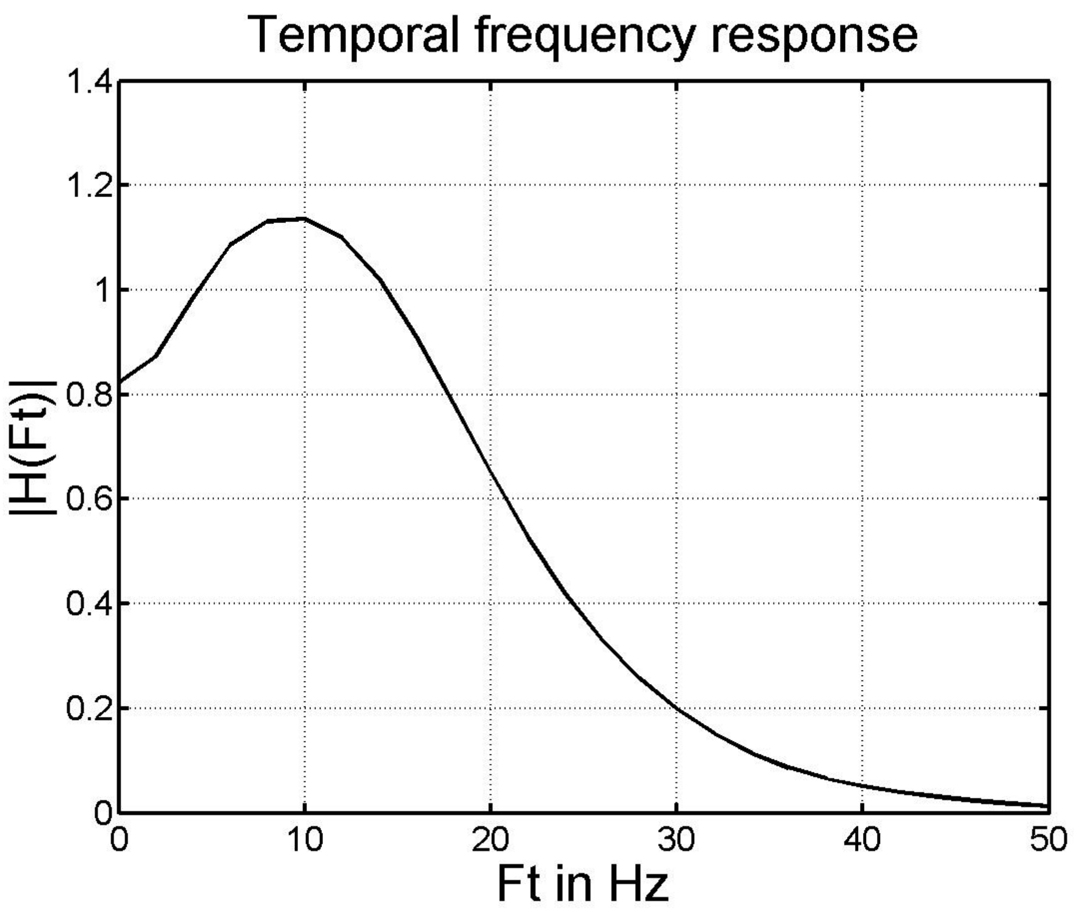
Video is time discrete in the temporal domain

More pictures/second affects:

- Motion portrayal
- Flicker

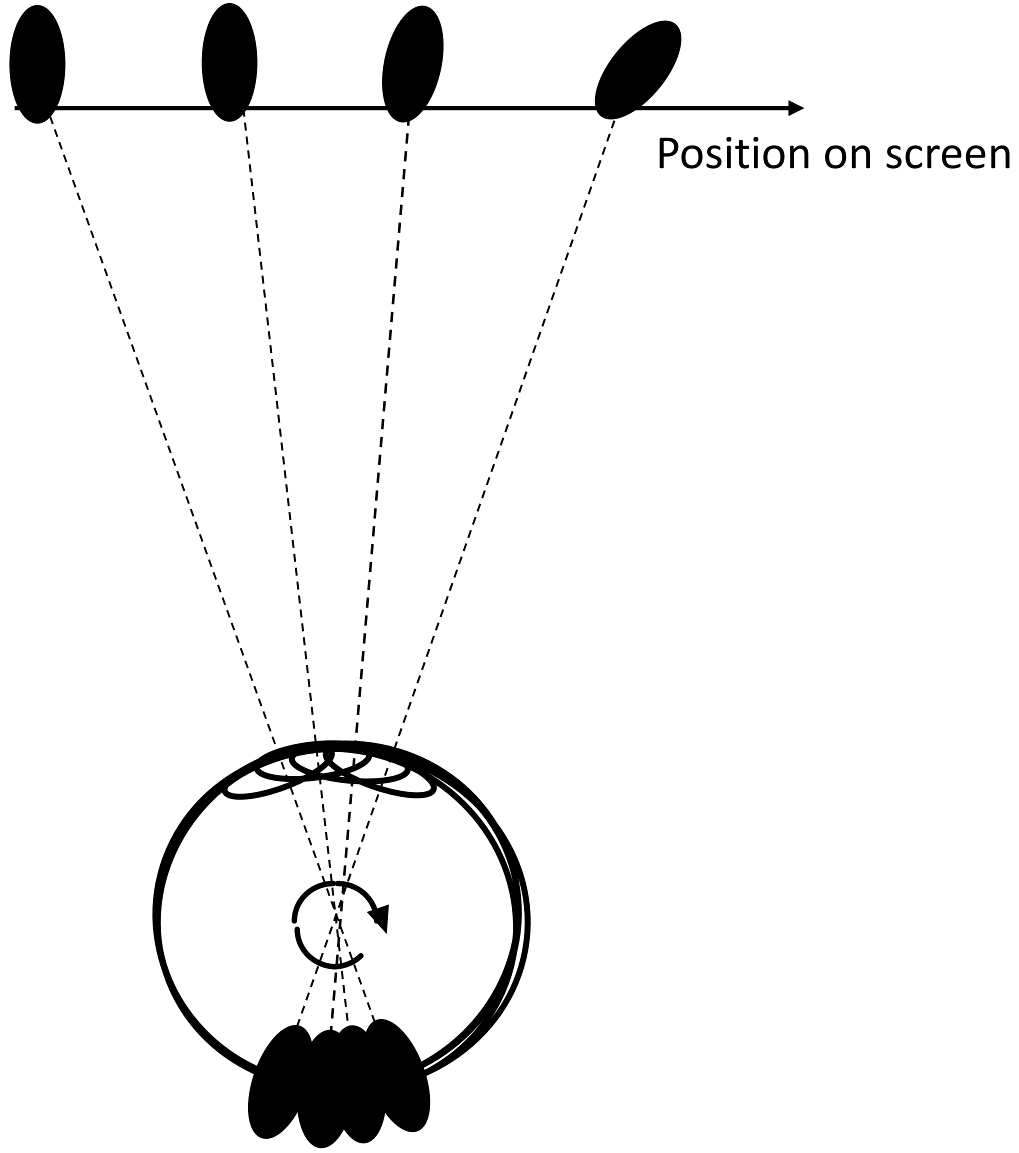


The retina of the eye has a slow response (integration effect)

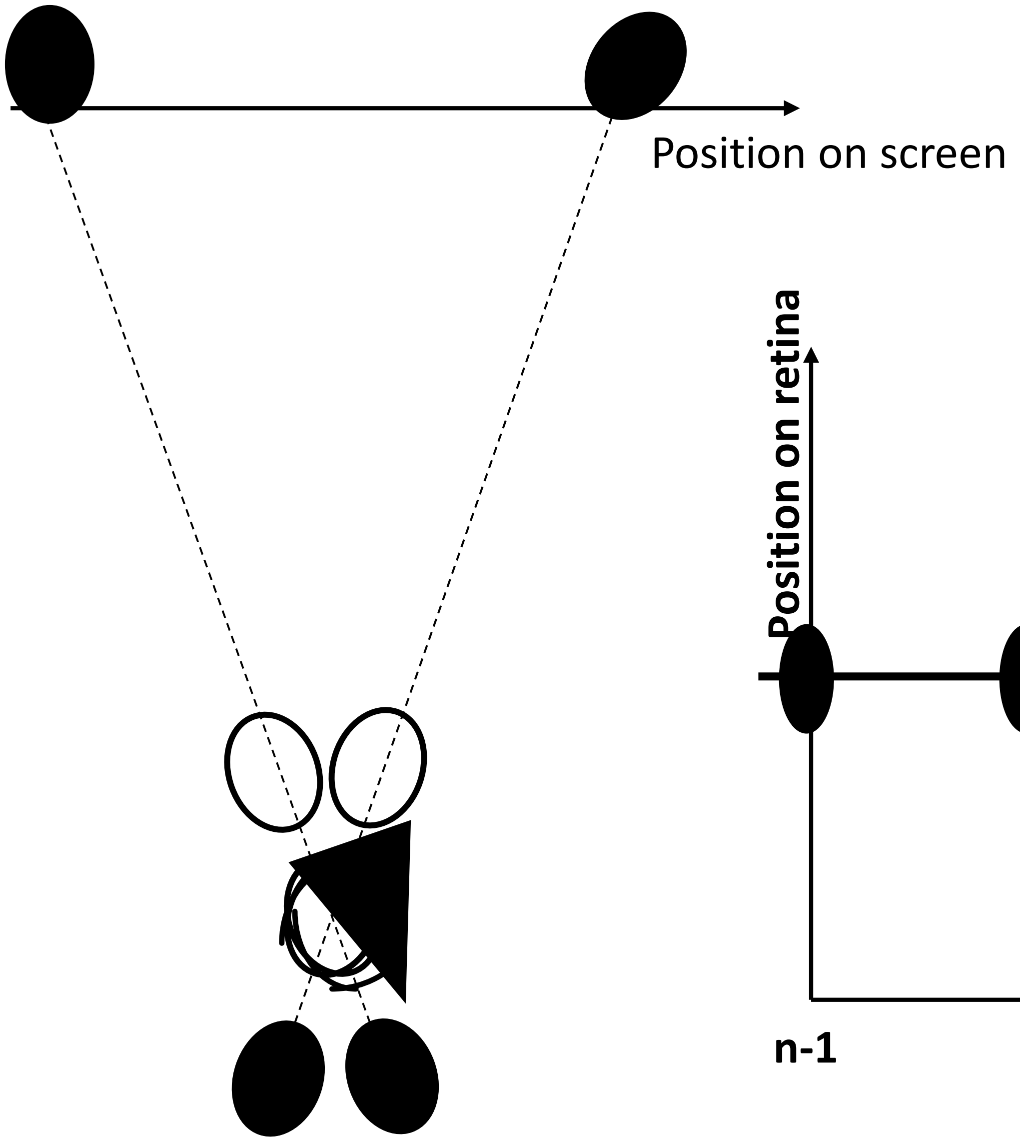


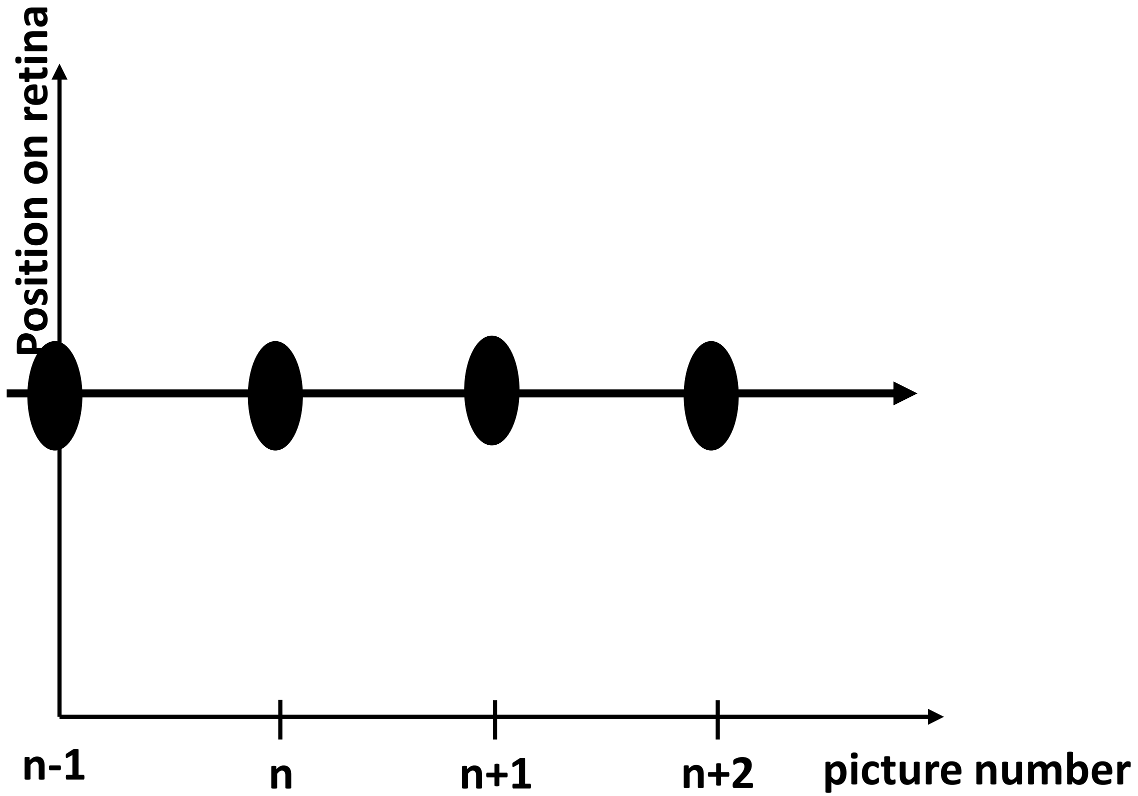
If we do not track the motion, objects get blurred

Object tracking with the eye



A moving ball on the retina of the tracking eye



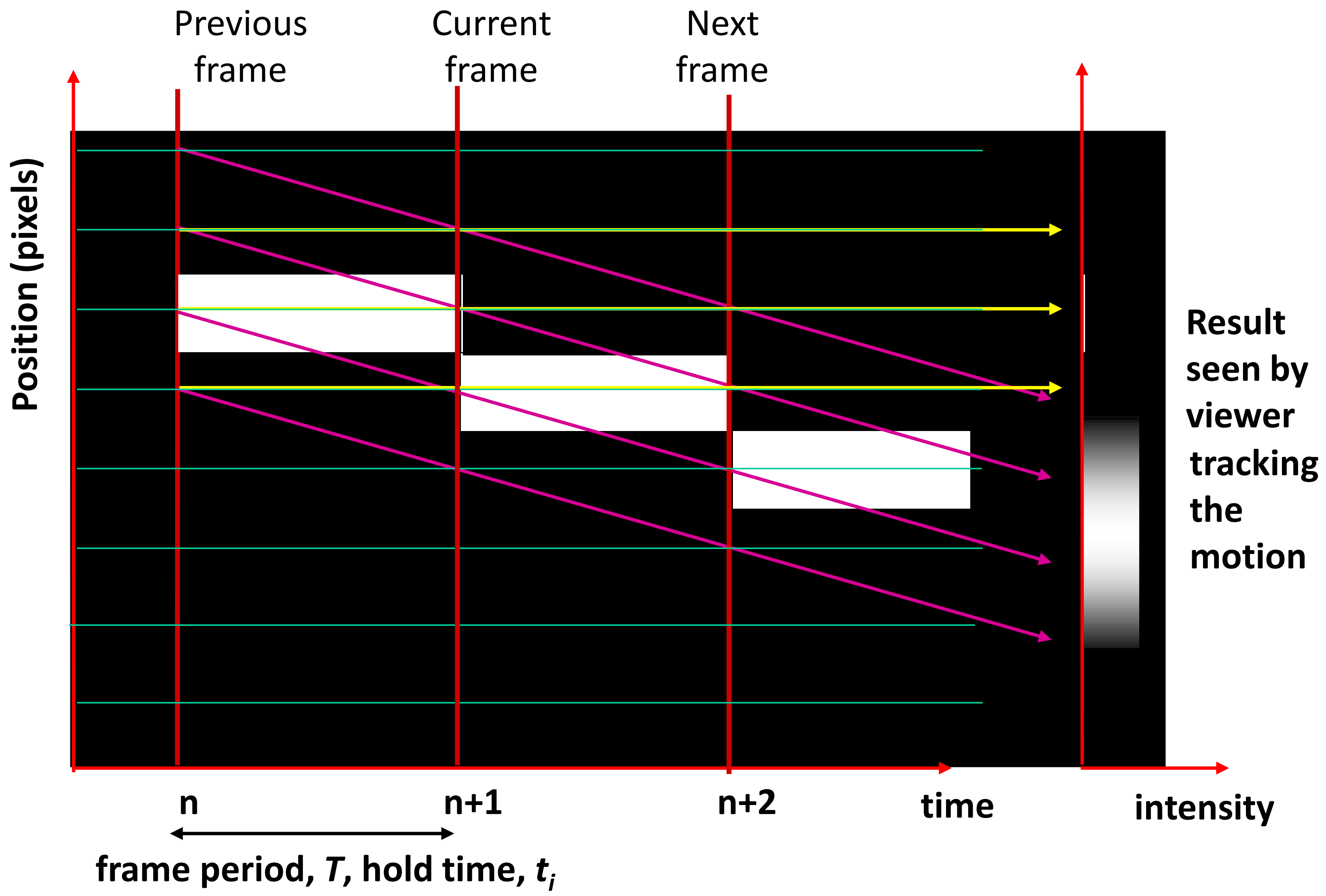


With correct tracking, sharp object

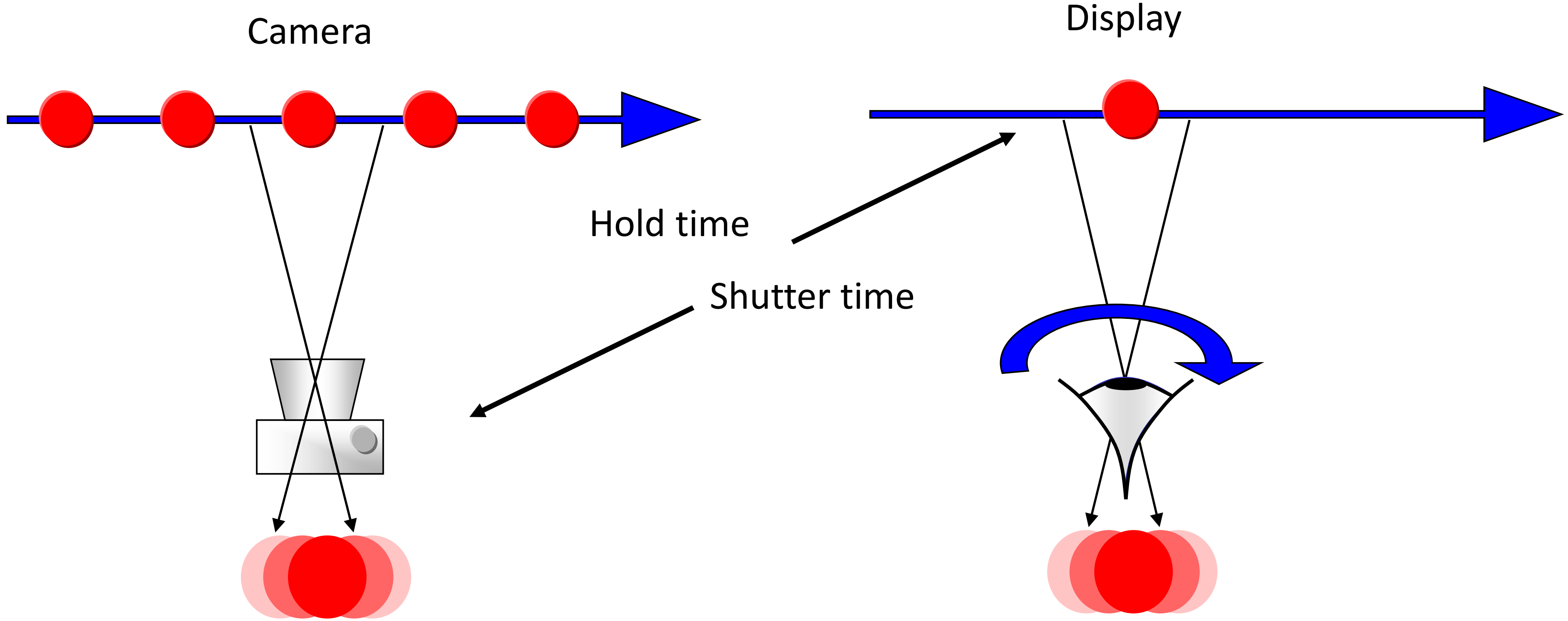
Consequences of motion tracking of the eye

- A display image is projected on a moving target (retina of the eye)
- If the eye moves substantially while the pixel is shown, the pixel size increases (blur)
- A pixel is only valid at a single point in space AND time, spatial or temporal spreading or mis-positioning degrades quality
- If pixels are not shown simultaneously, there relative position is modified by the eye movement
- A single TV-image need not be complete, if soon enough complementary information is shown (interlace, colour sequential display)
- The quality of individual images is irrelevant: **Photography ≠ Video!**

Motion rendering LCD



Motion blur on display and camera



The object moves relative to a stationary camera that integrates the image during the shutter time

The eye smoothly follows a moving object that remains stationary during the display hold time

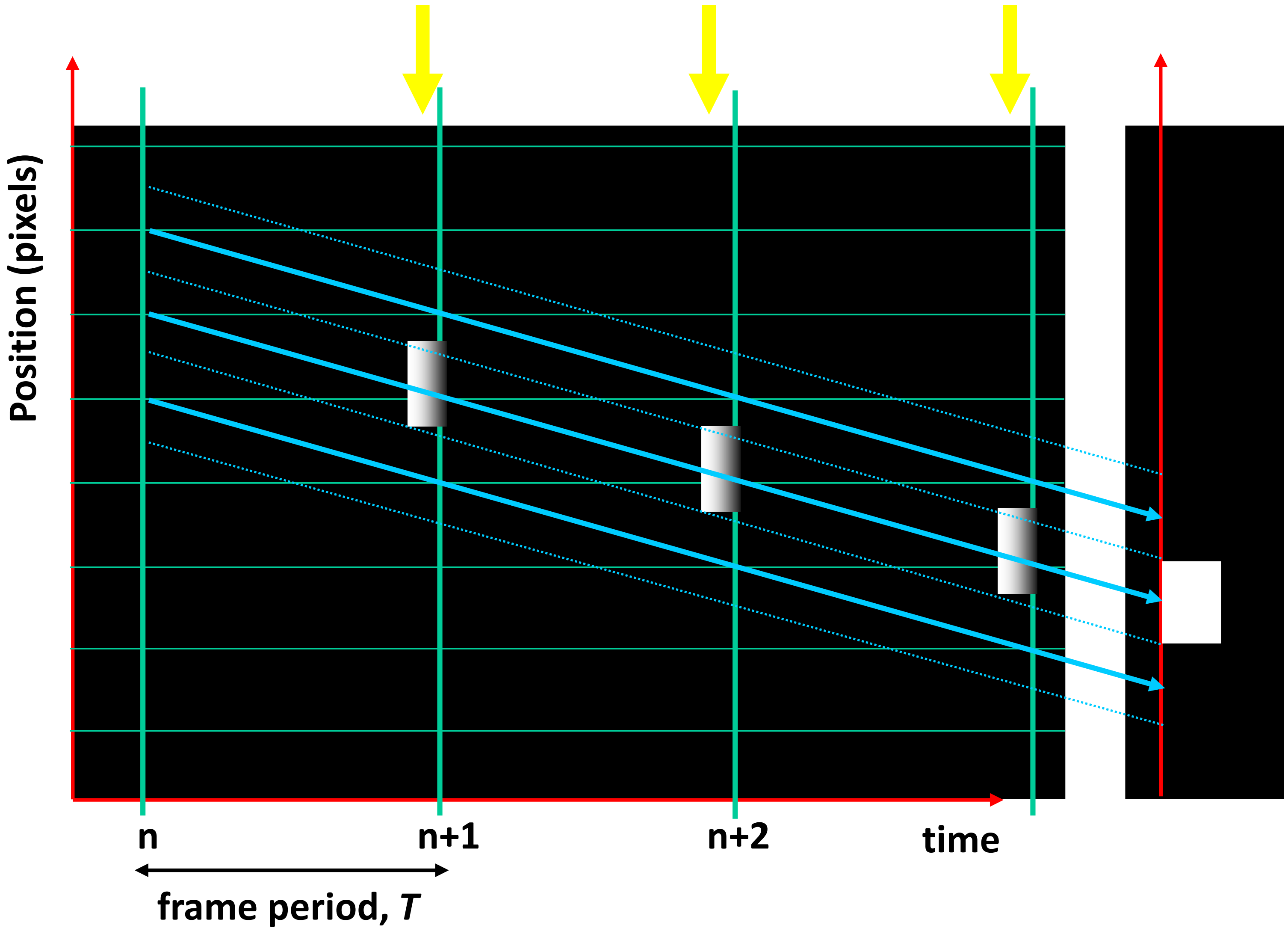
Dynamic resolution – Sharpness of moving images

Two phenomena with the same result, i.e. motion blur:

Object moves while shutter of photo-camera is open…

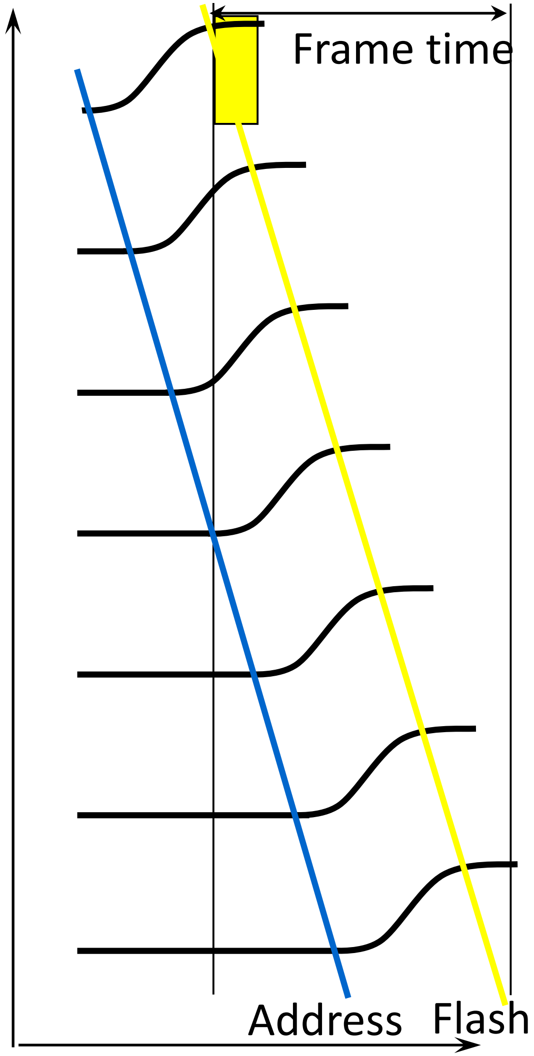
Eye moves over TV-screen, while image remains the same during picture period…

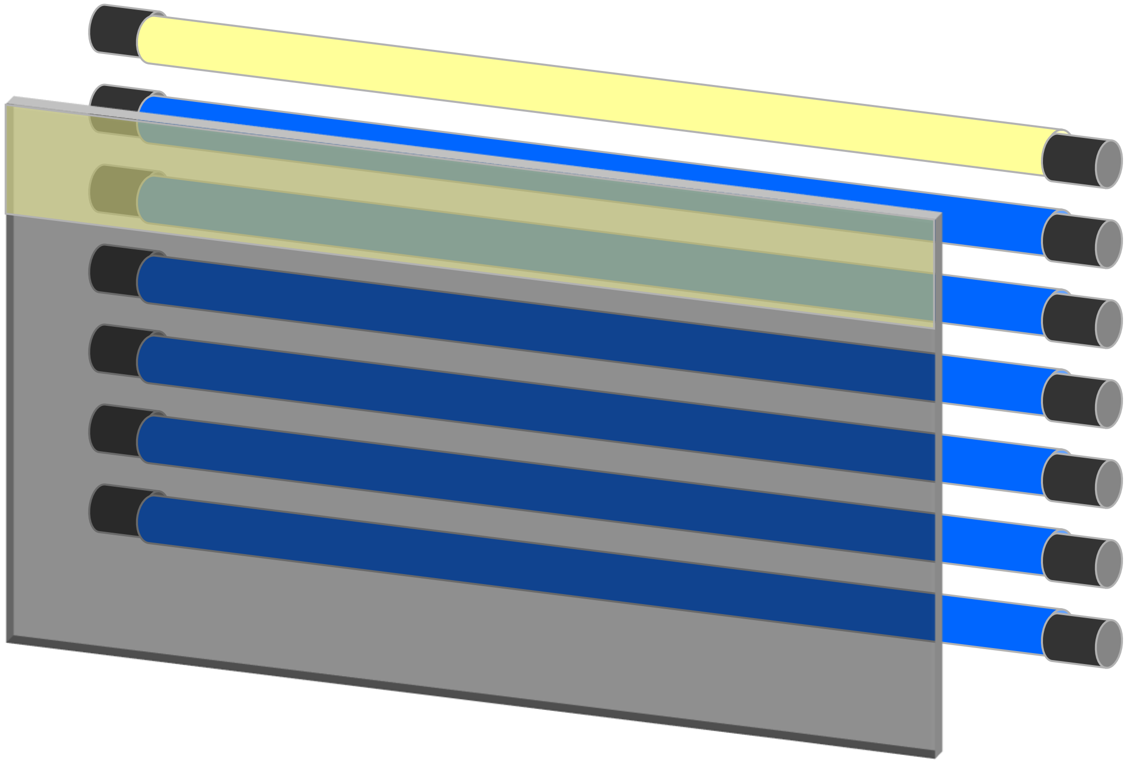
Solution 1: Motion rendering, flash backlight when LCD stable



Result seen by viewer tracking the motion

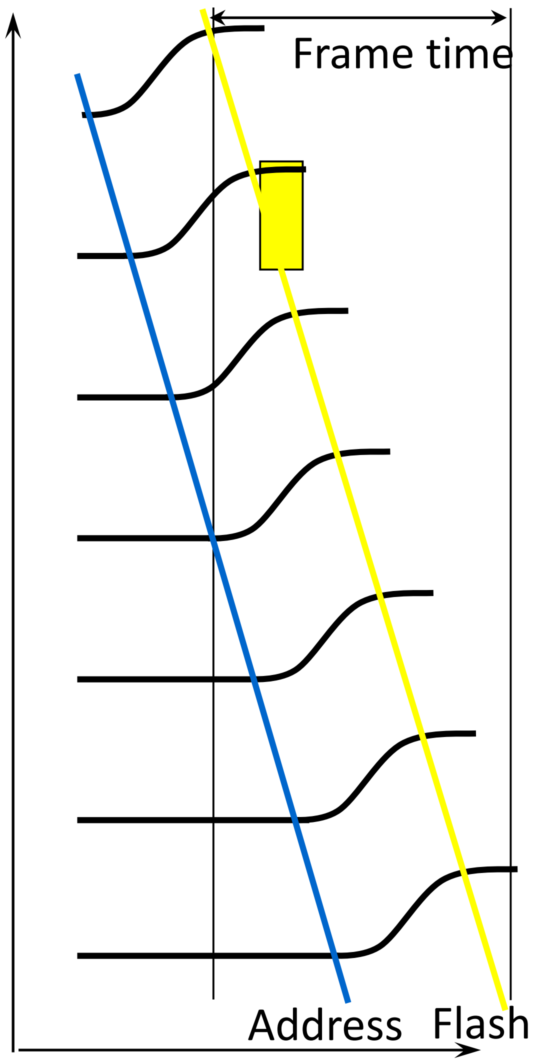
Scanning Backlight, practical implementation

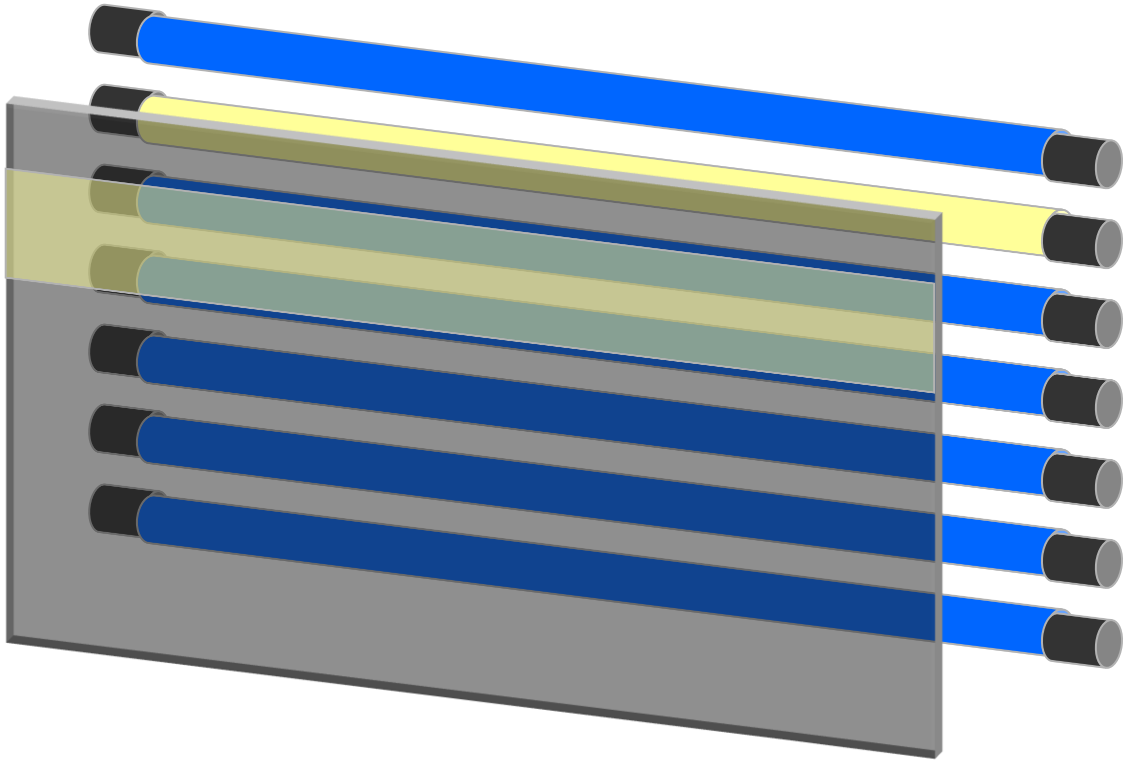




The scanning speed is synchronized with the speed of entering information to the screen.
Flash the backlight when LC reaches desired value

Scanning Backlight





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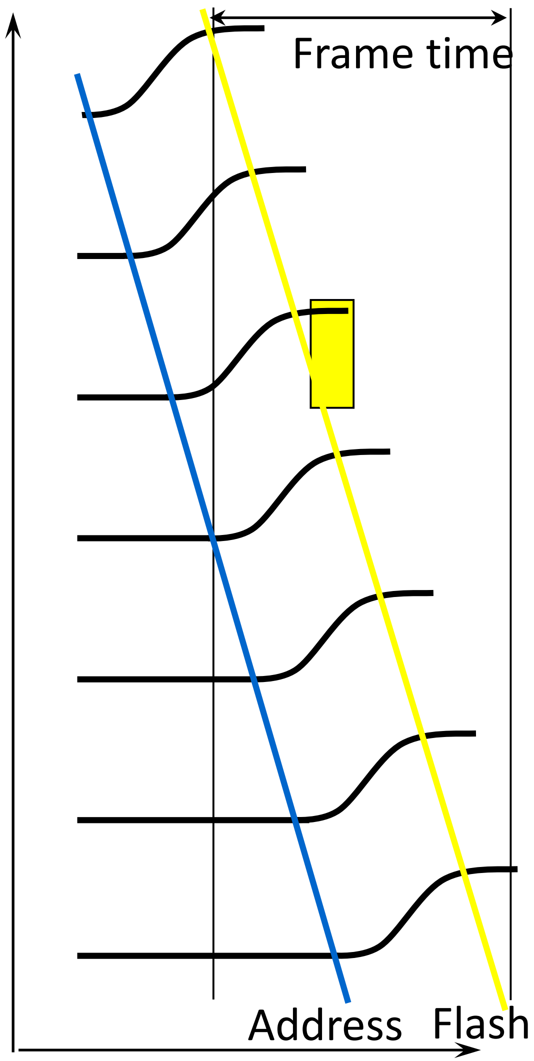
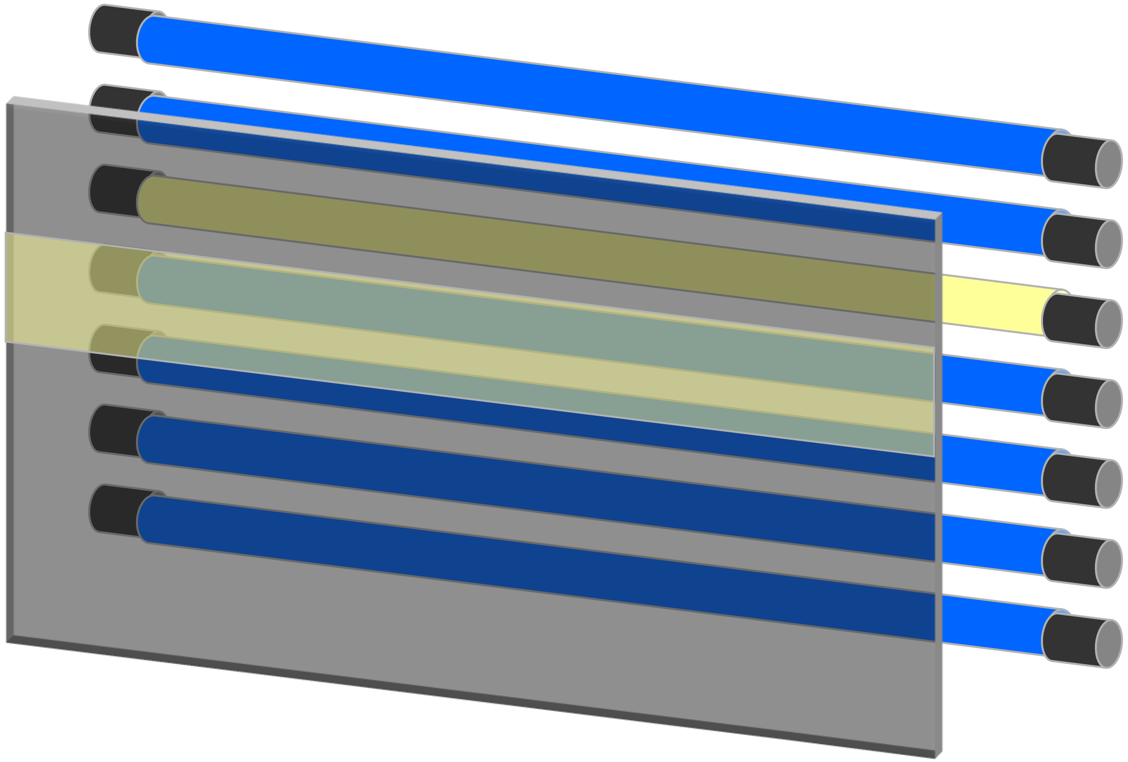
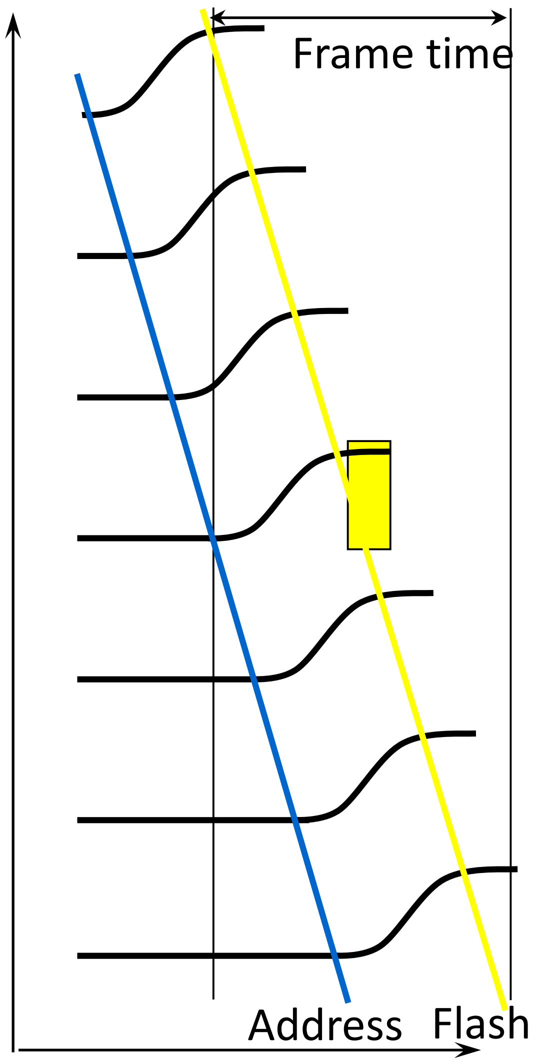
Scanning Backlight

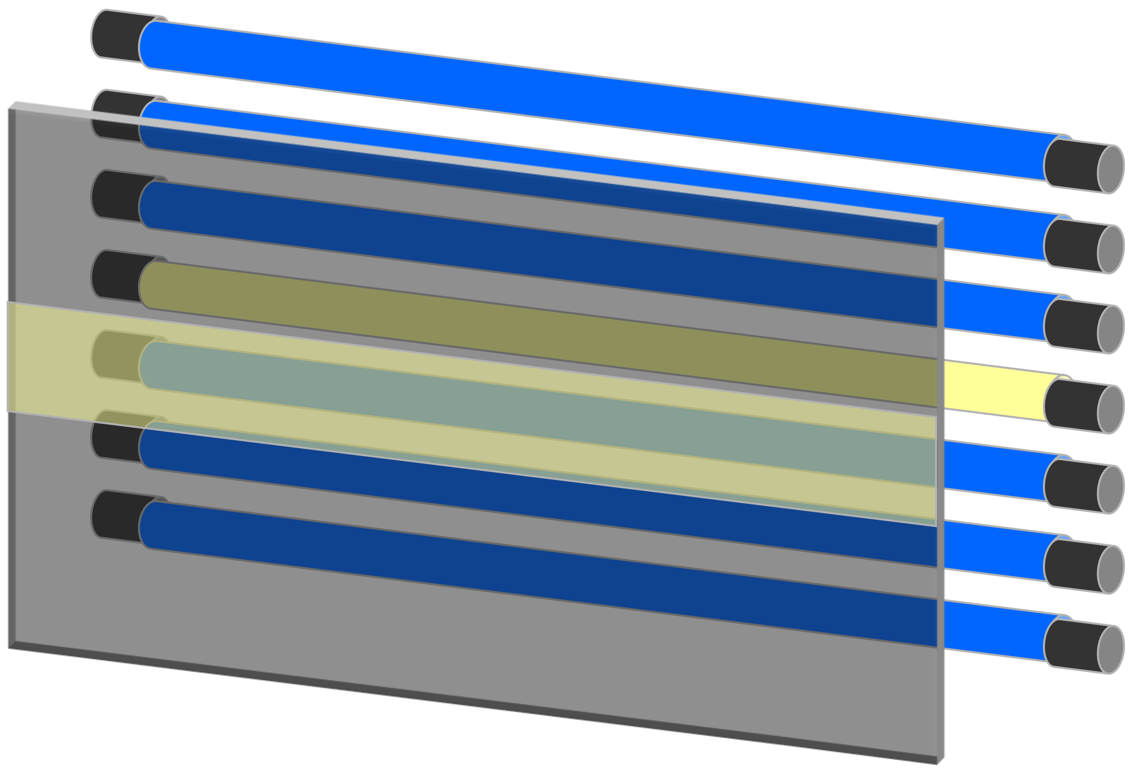




The scanning speed is synchronized with the speed of entering information to the screen.
Flash the backlight when LC reaches desired value

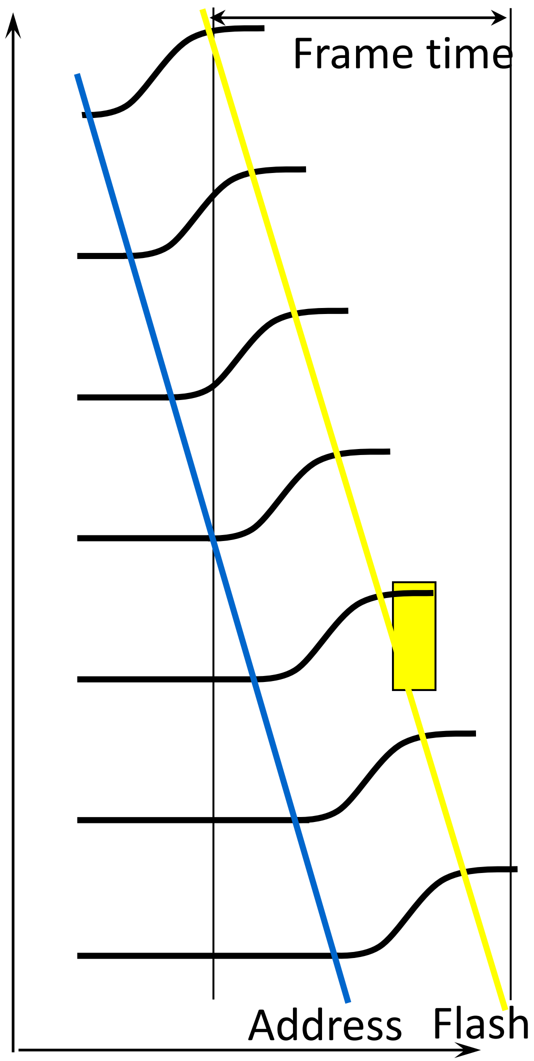
Scanning Backlight

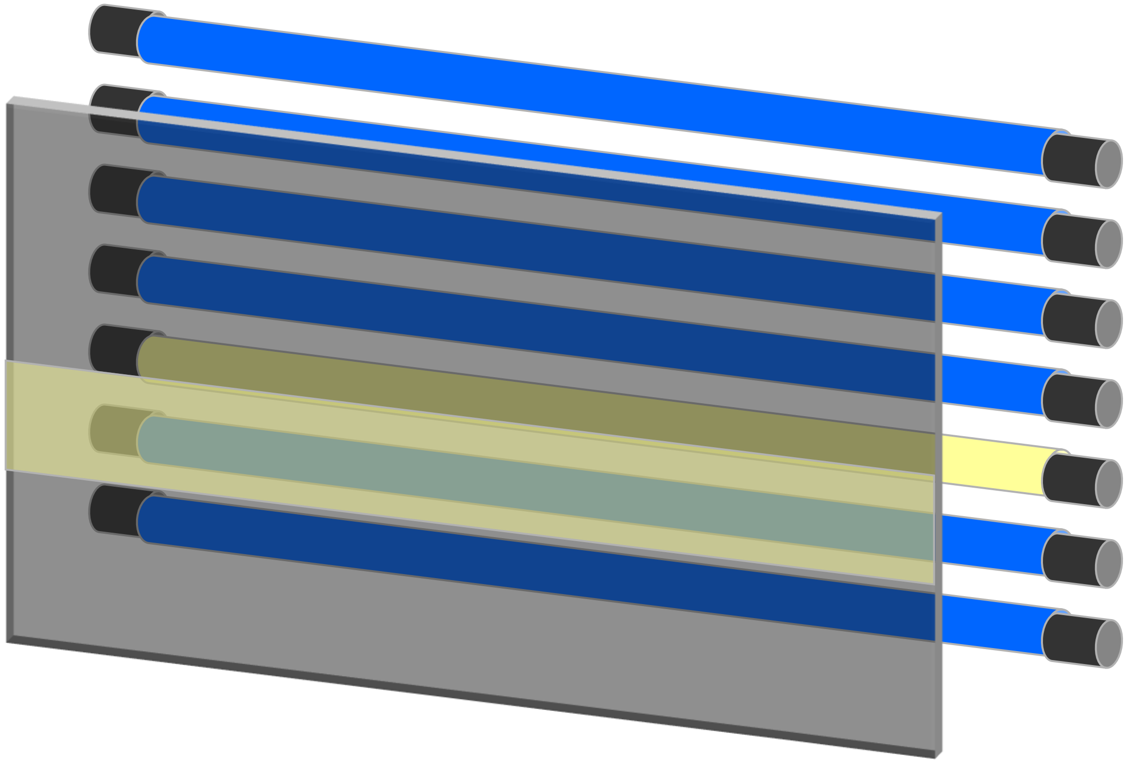




The scanning speed is synchronized with the speed of entering information to the screen.
Flash the backlight when LC reaches desired value

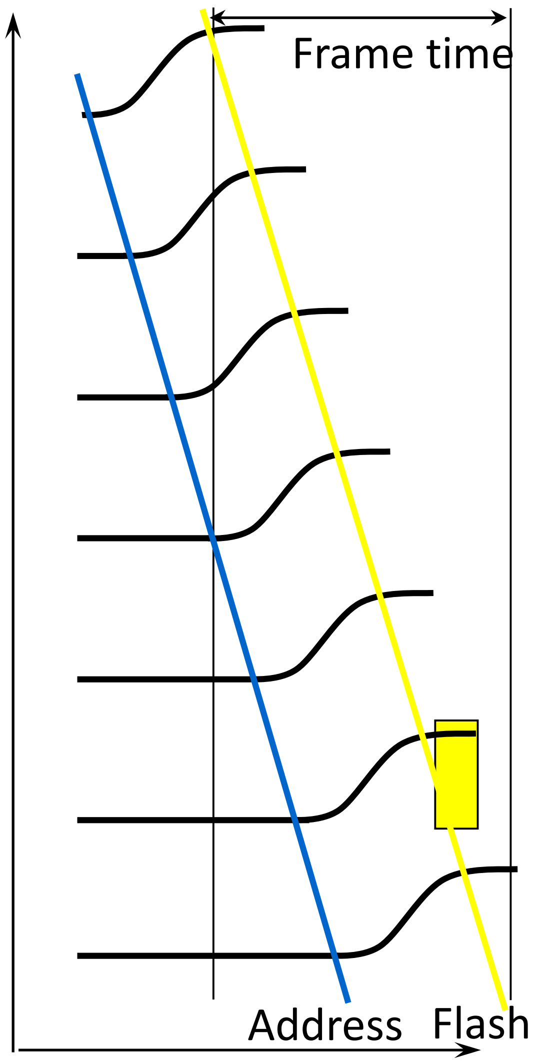
Scanning Backlight

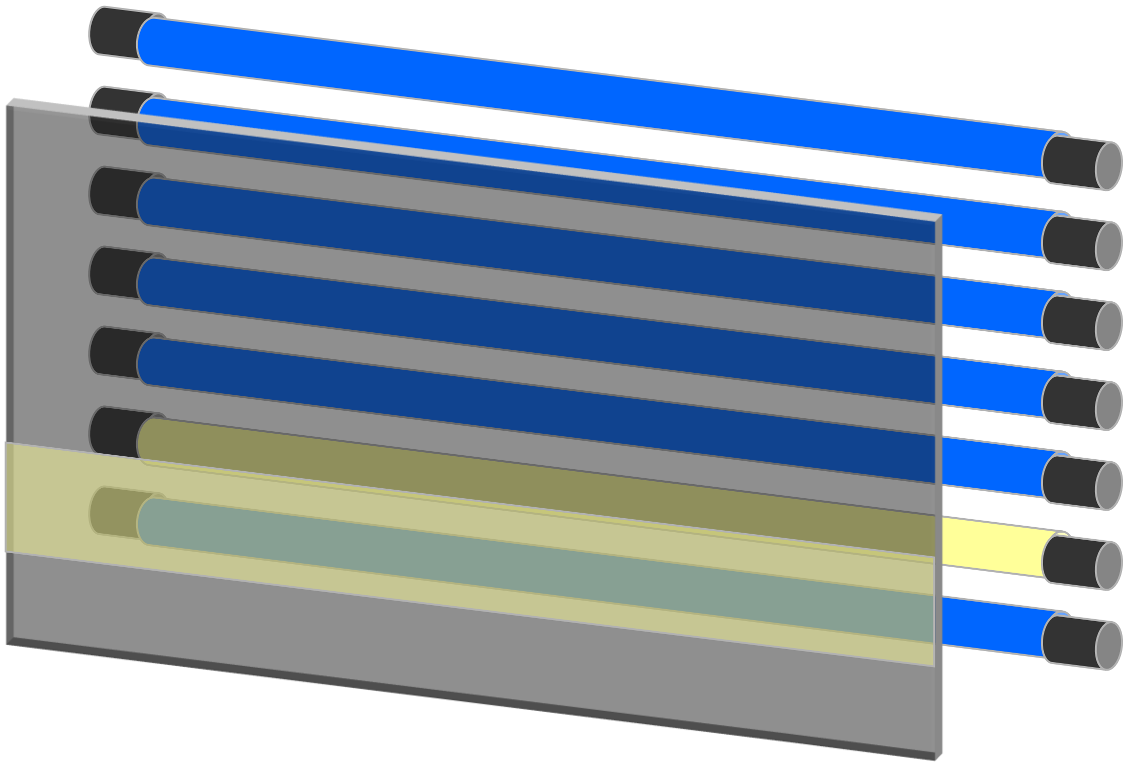




The scanning speed is synchronized with the speed of entering information to the screen.
Flash the backlight when LC reaches desired value

Scanning Backlight





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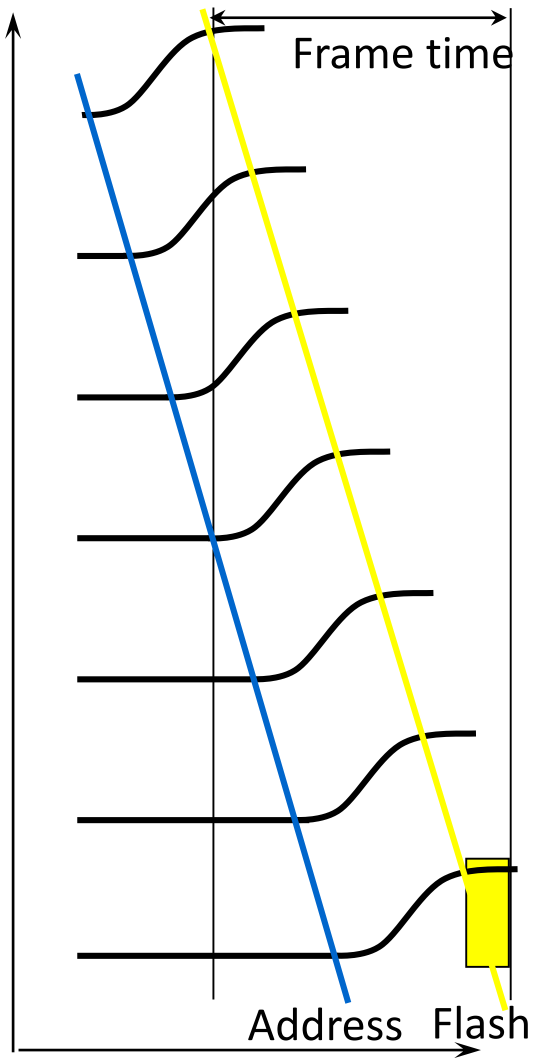
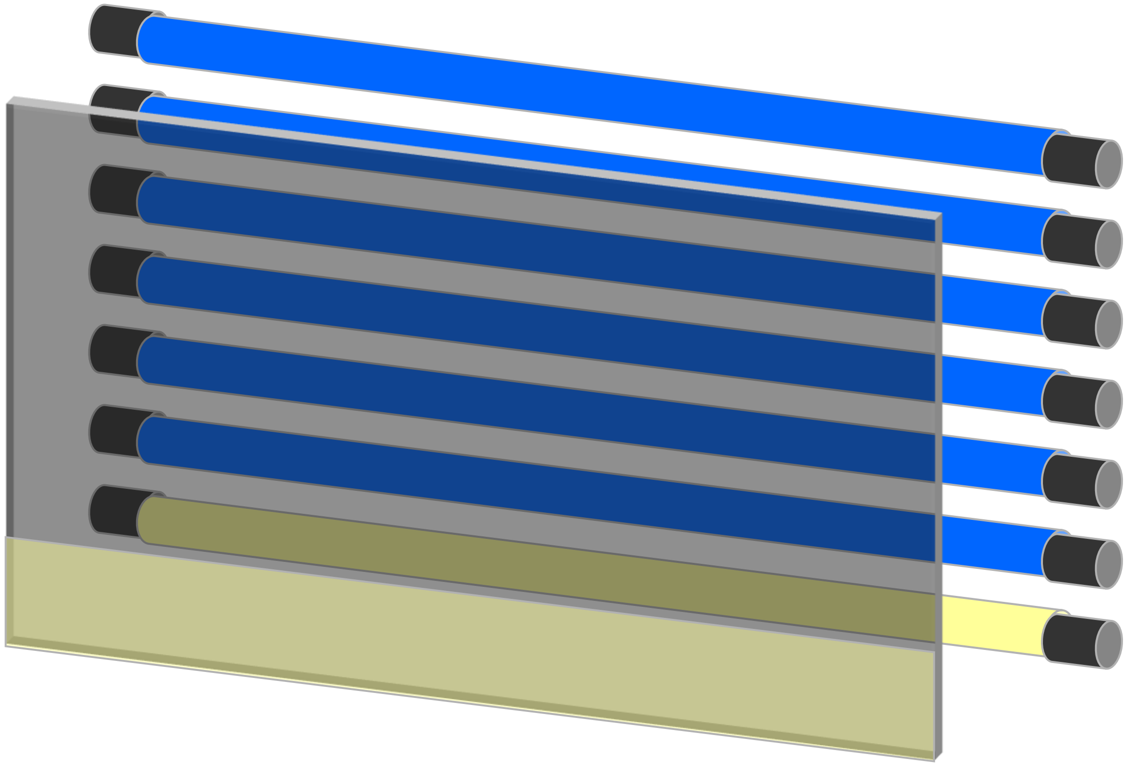
Scanning Backlight





The scanning speed is synchronized with the speed of entering information to the screen.
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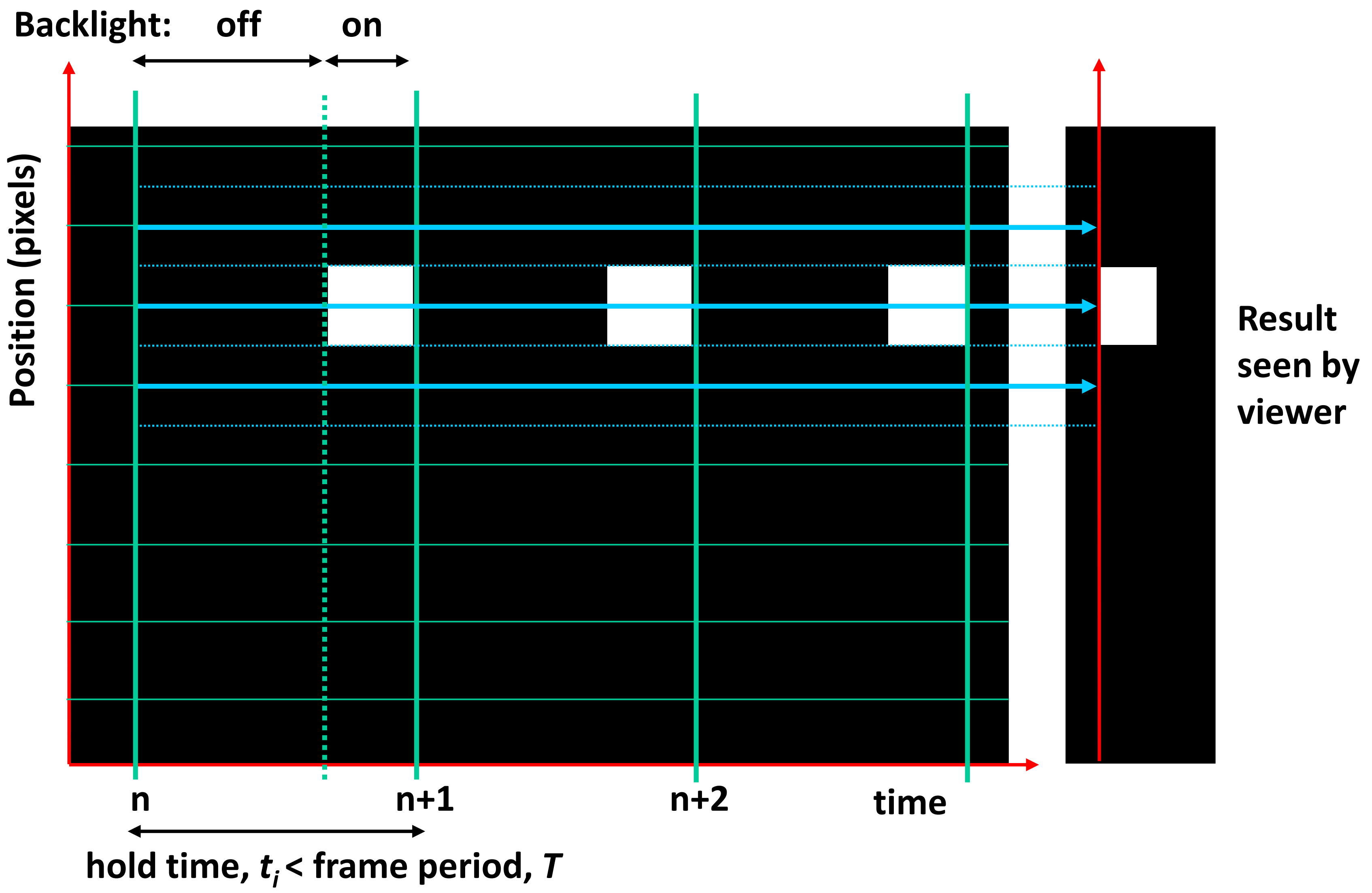
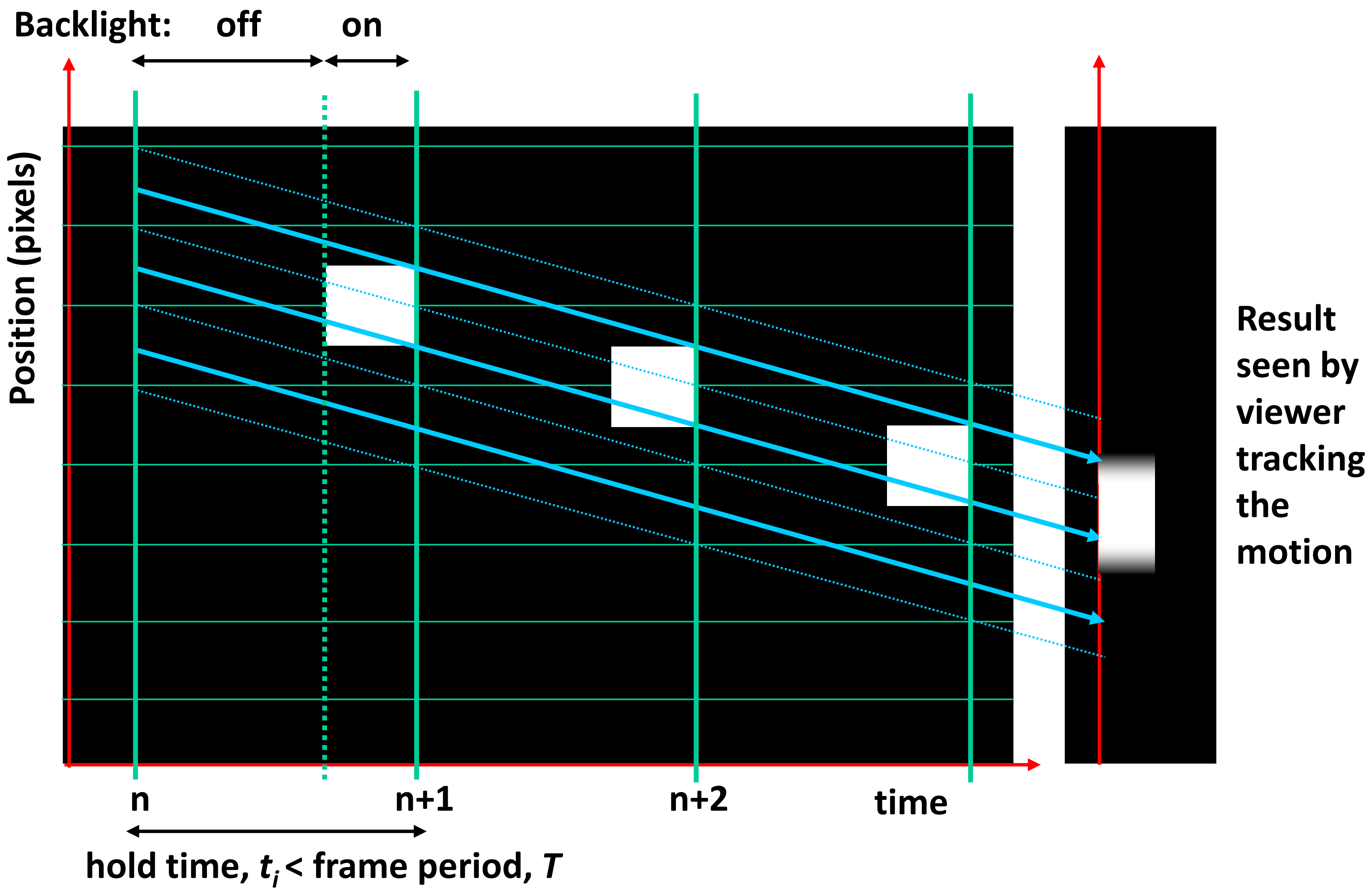
Motion rendering, scanning backlight LCD



Motion rendering, scanning backlight LCD



This is what it looks like

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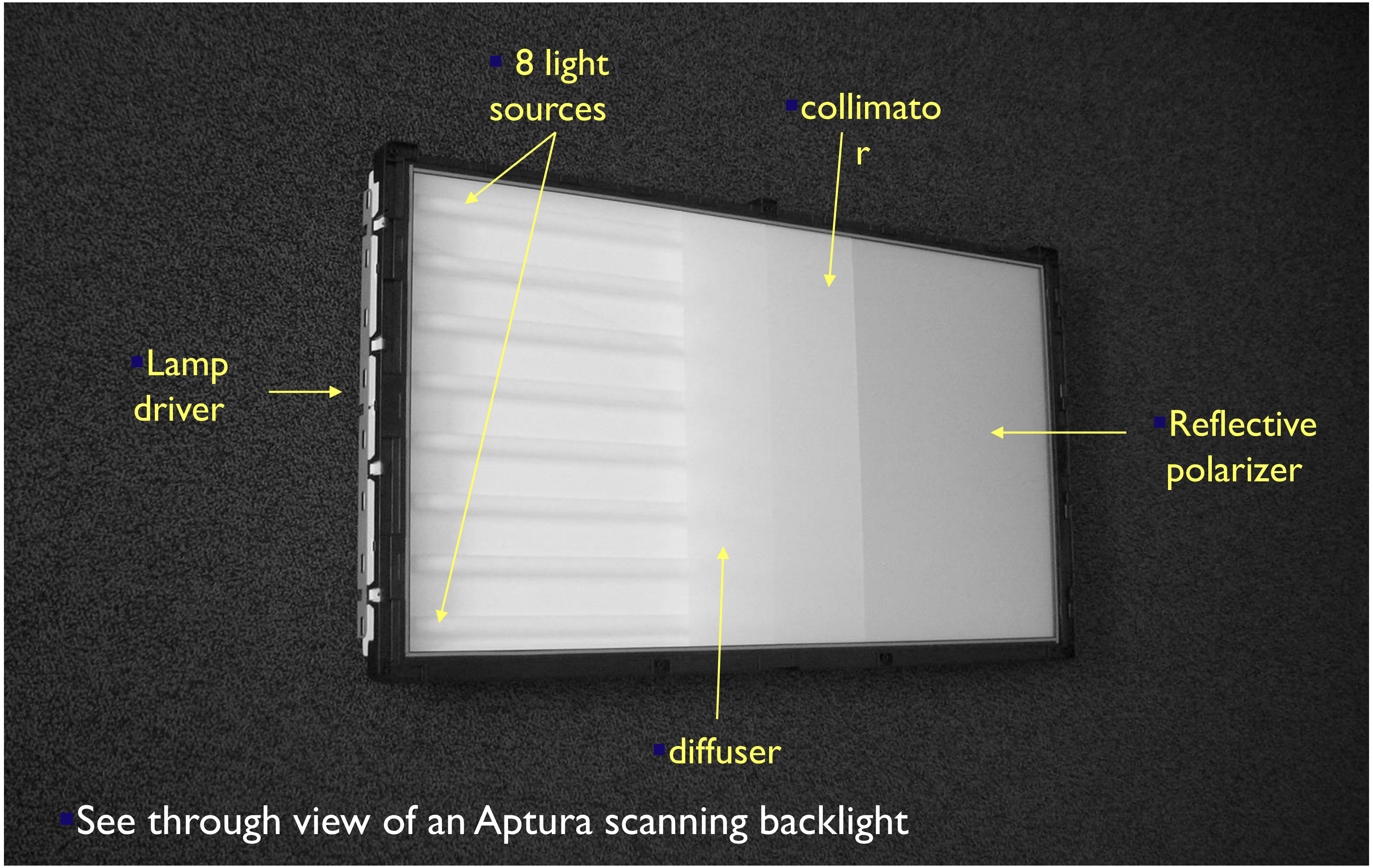
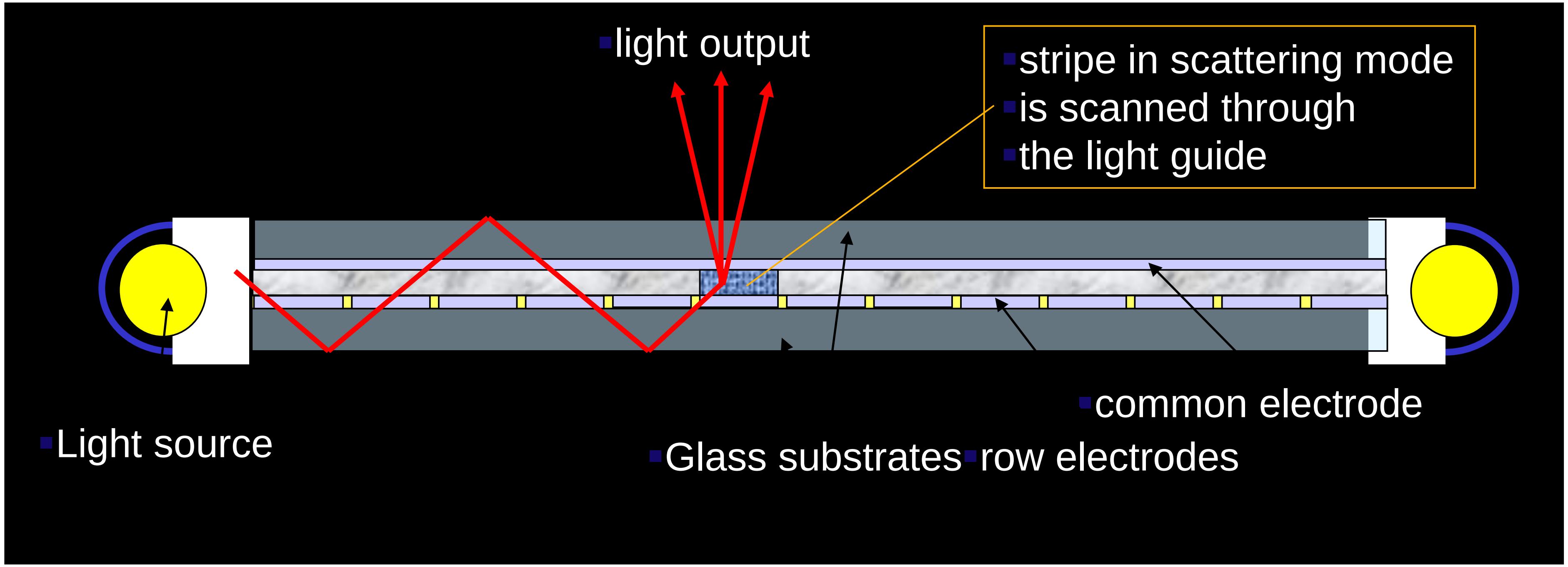
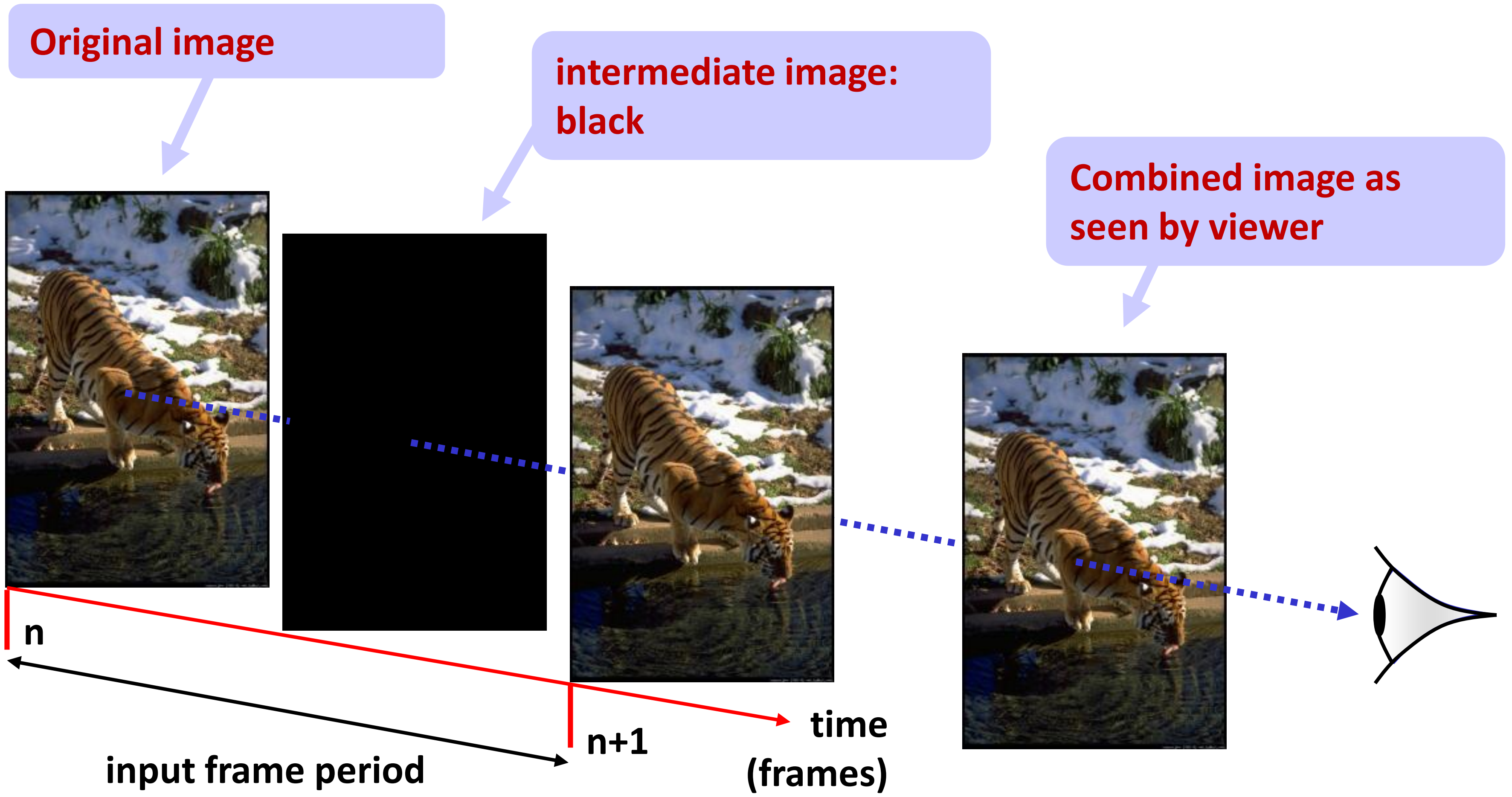


Alternative: Scanning Highlighting Backlight

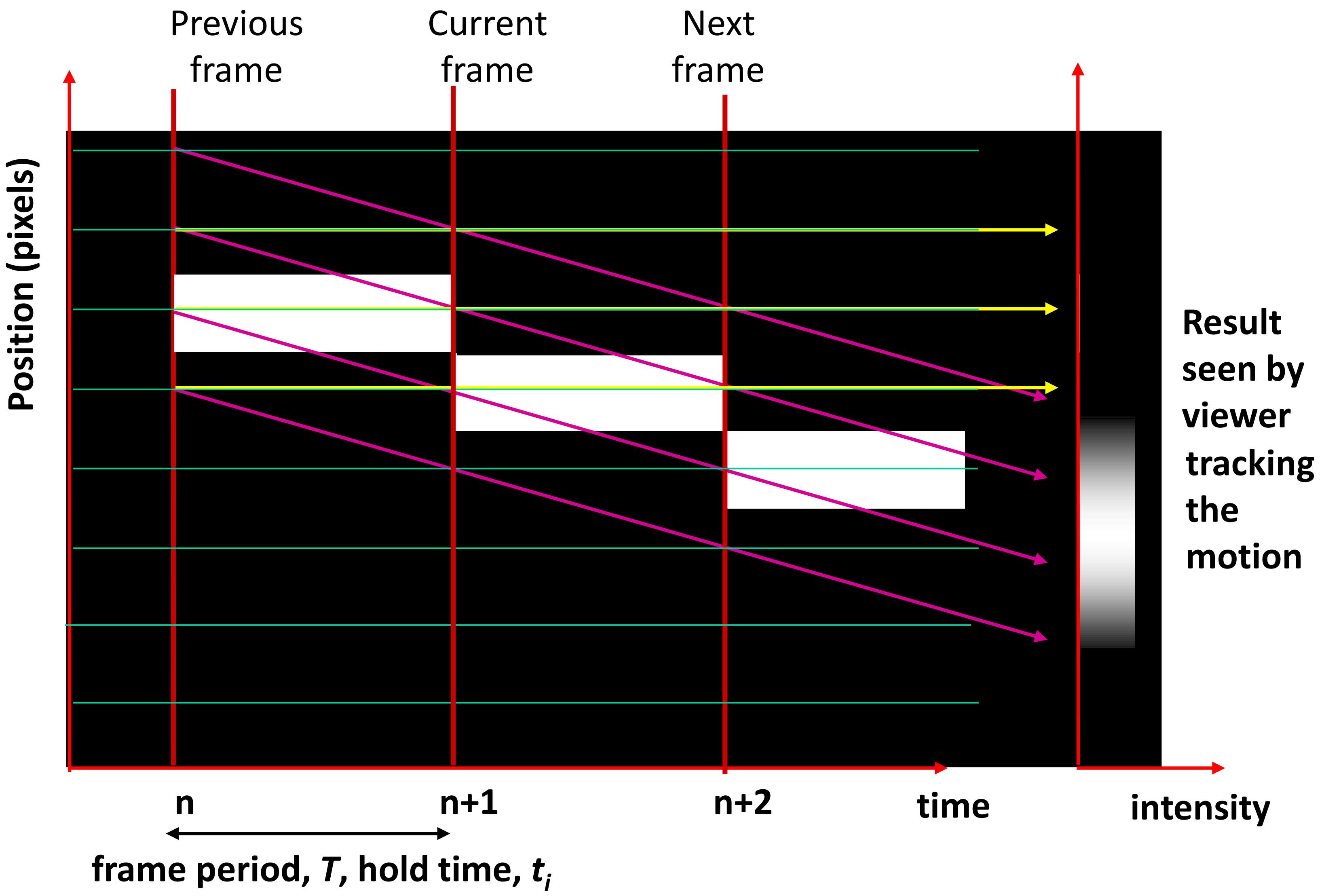


Solution 2 for motion: change picture rate

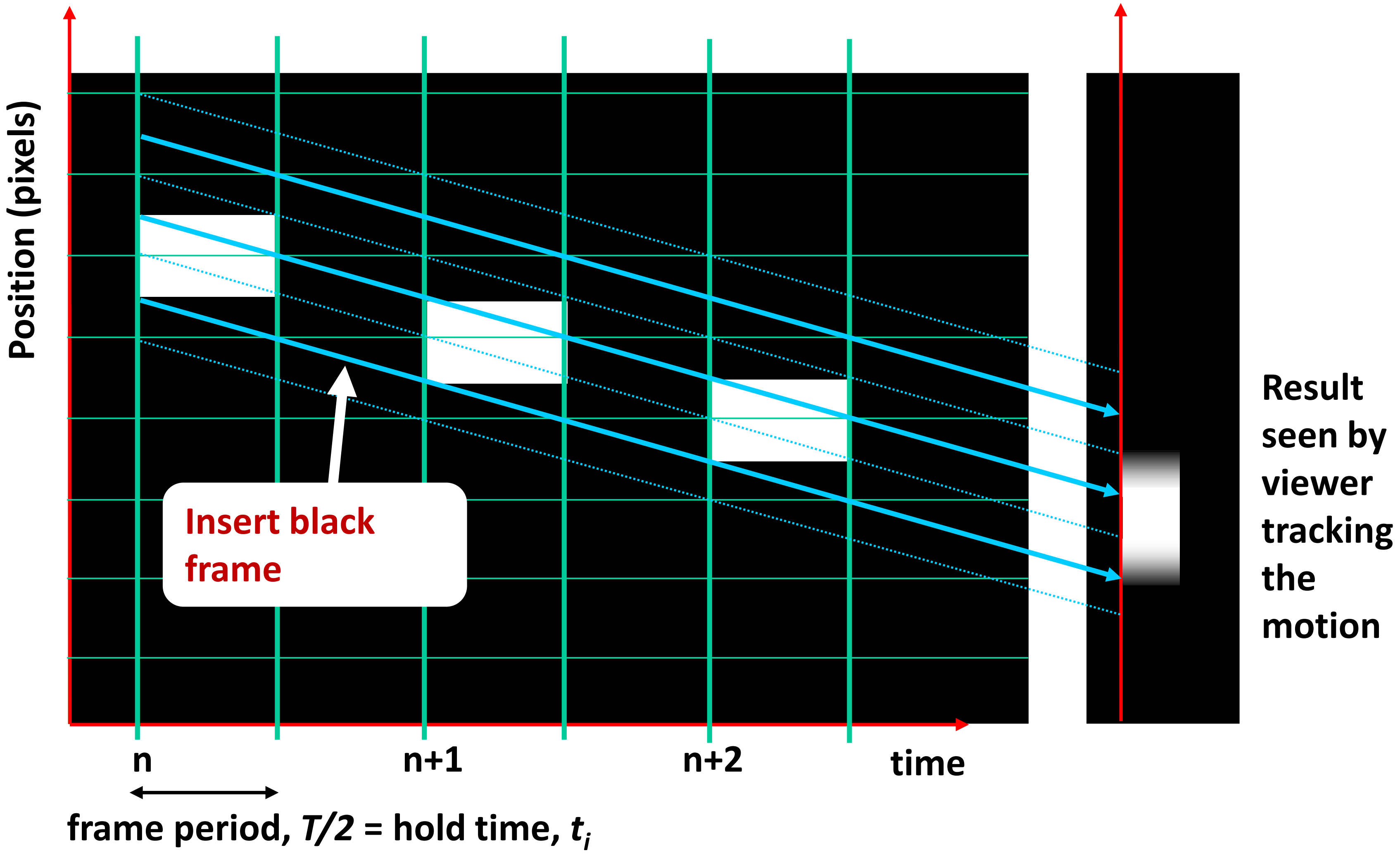
- Shortening the light emission time of each frame decreases motion blur (insert black frames)



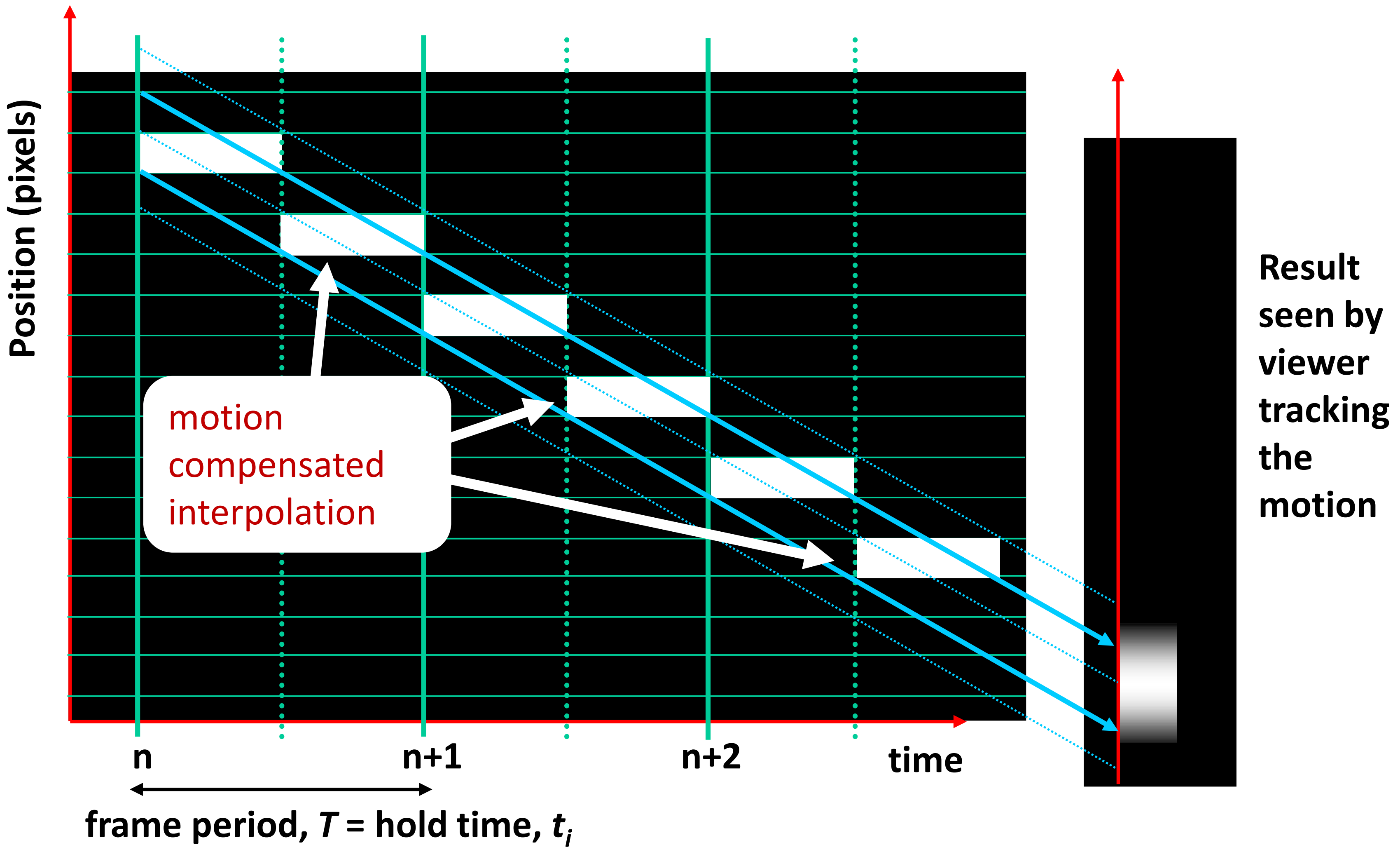
Motion rendering standard LCD



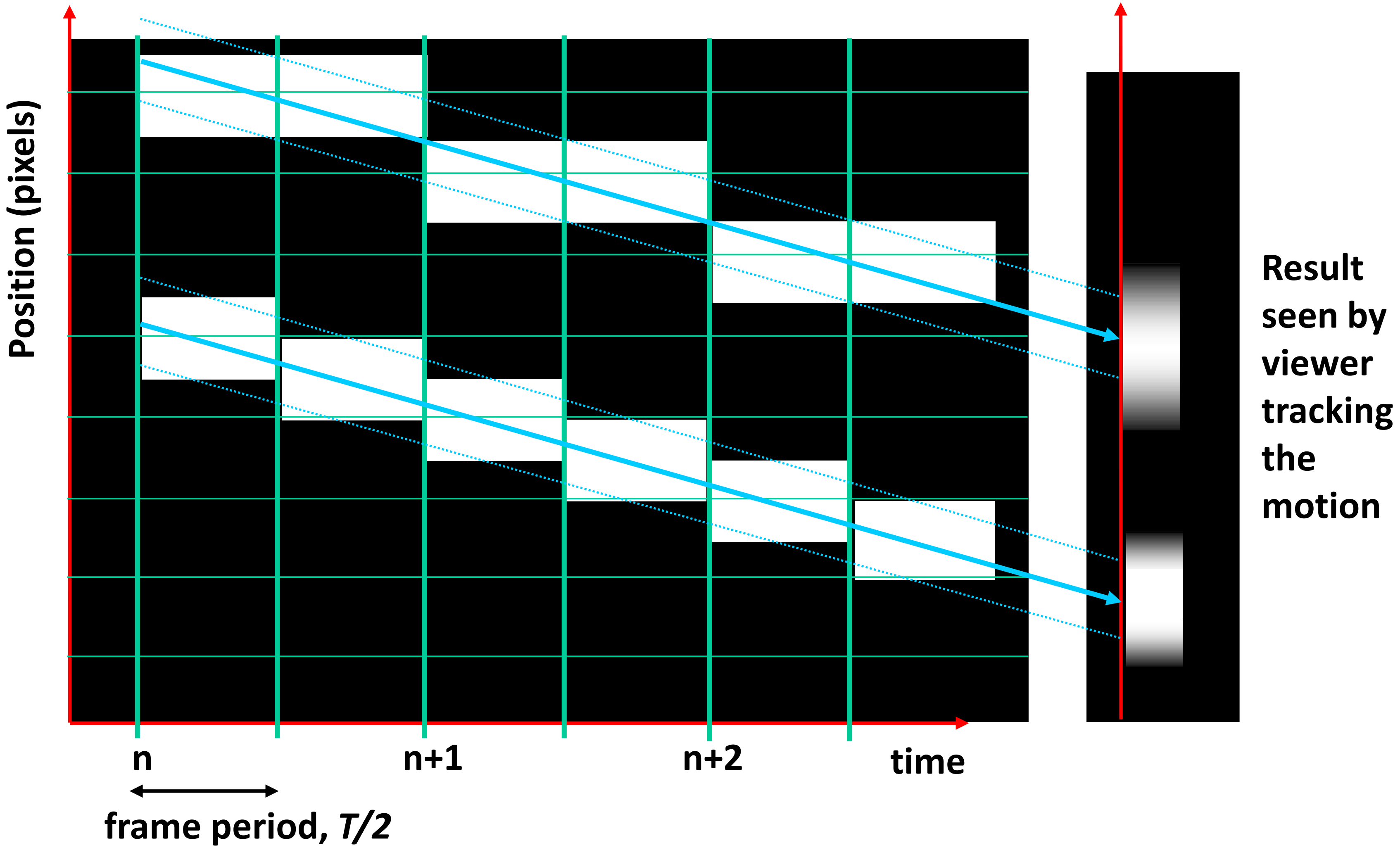
Motion rendering, black frame insertion



Improved option: Motion compensated picture rate doubling

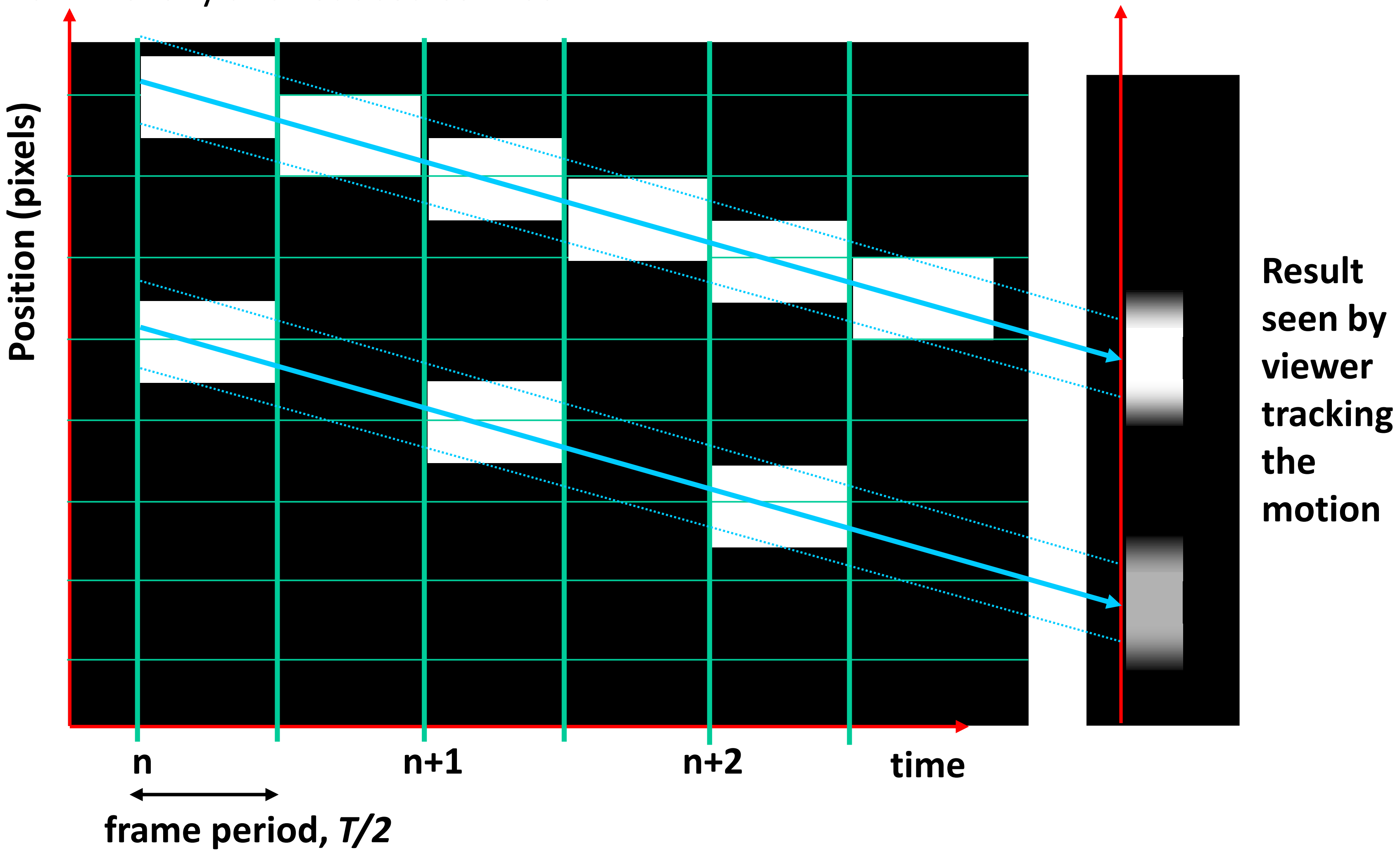


Improvement with MC picture-rate doubling



Blur of BFI same as MC picture-rate doubling

- But with half intensity and reduced contrast!



Options to improve motion on LCD

1. Pulsing backlight

2. Shorten picture time (more pictures/second)

3. Sharpening dependent on object velocity