FACULTY OF ENGINEERING AND ARCHITECTURE

ELECTRONICS AND INFORMATION SYSTEMS DEPARTMENT
LIQUID CRYSTALS AND PHOTONICS RESEARCH GROUP

LIQUID CRYSTALS AND LIGHT EMITTING MATERIALS FOR PHOTONIC APPLICATIONS

Kristiaan Neyts April 2018 Lecture series at WAT in Warsaw

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nb-photonics
Center for Nano- and Biophotonics
Ghent University

Liquid Crystals and Photonics

OVERVIEW

Display applications (6h)

The human eye
Display characteristics
Liquid crystal display characteristics
Direct drive and active matrix
Direct view displays
LCD backlight
Projection displays
Spatial light modulator
OLEDs

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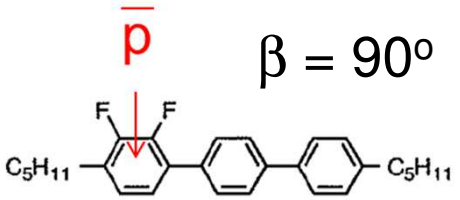
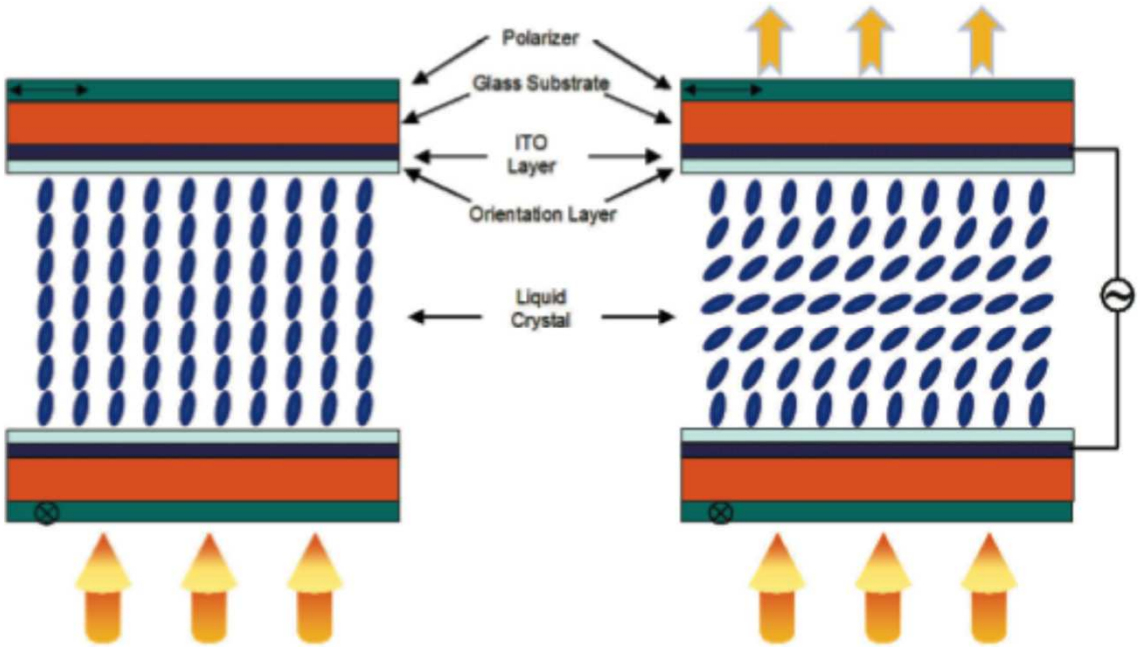
VERTICALLY ALIGNED NEMATIC (VAN)

Initially vertically aligned, and $\Delta\varepsilon < 0$
with particular alignment material





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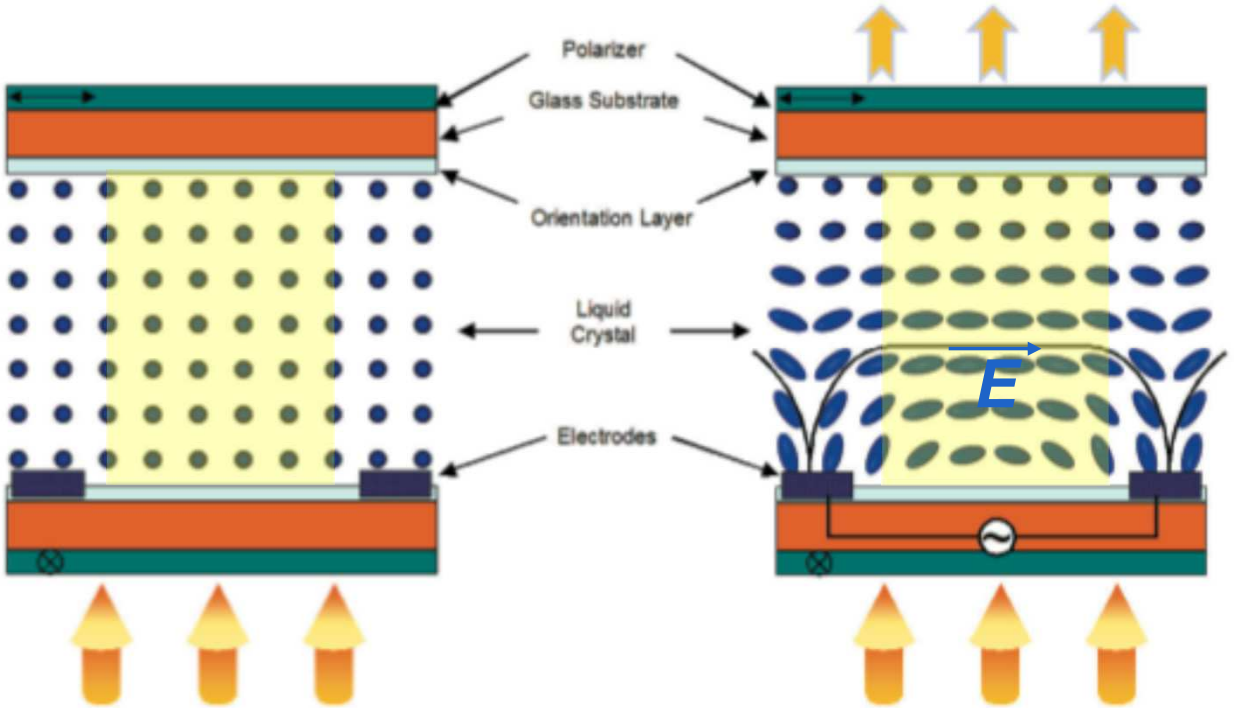
IN PLANE SWITCHING (IPS) MODE

initially: director homogeneous

with voltage: director reorients in plane



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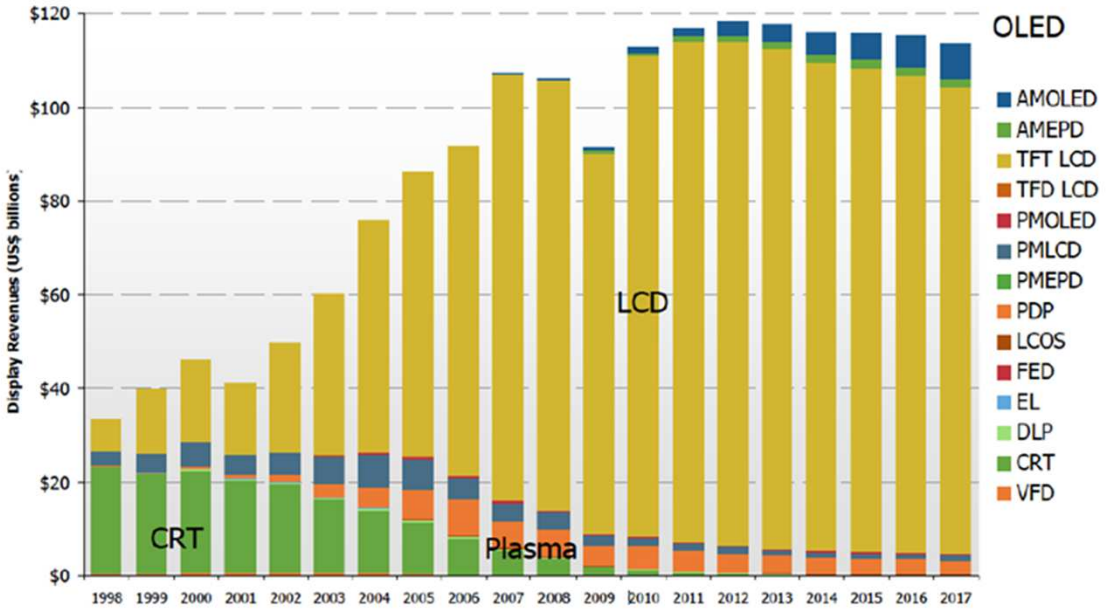
DISPLAY CLASSIFICATION

Revenue by display type: trends

Recent developments:

- LCD
- OLED
- Touchscreens
- 3D displays



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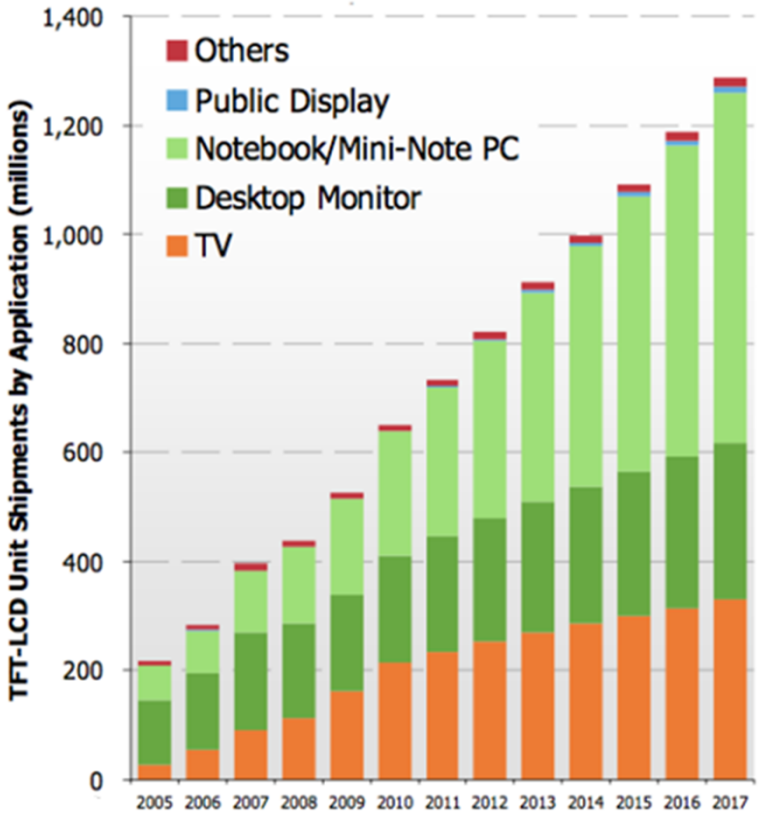
DISPLAY CLASSIFICATION

Display by number of units: trends

for TFT-LCD



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DISPLAY CLASSIFICATION

Classification according to content and size

- LIC (low-information-content): watches, clocks
- HIC (high-information-content): matrix display, moving images
  - Small (mobile phone, tablet, PC monitor)
  - Large (TV)
  - Huge (cinema, outdoor, professional)

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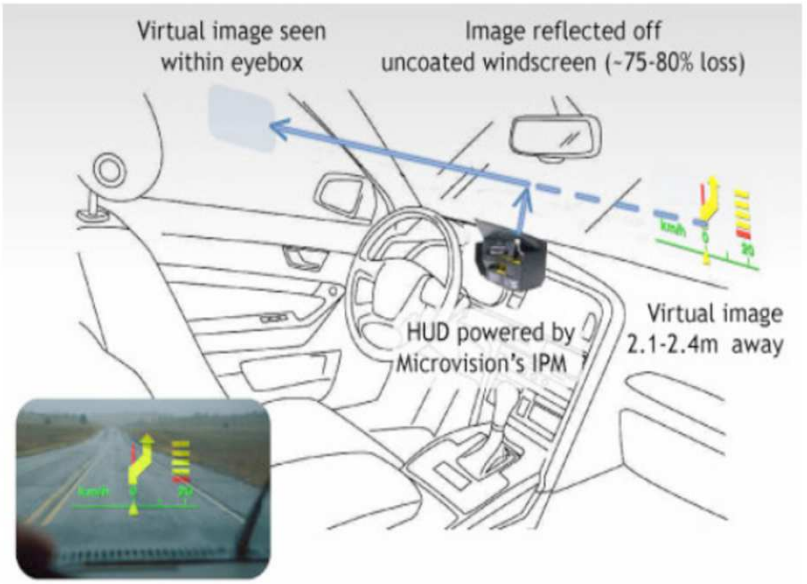
DISPLAY CLASSIFICATION

Classification according to type of screen

- Direct view
- Projection
- Virtual screen
  (e.g. HUD, VR goggles)



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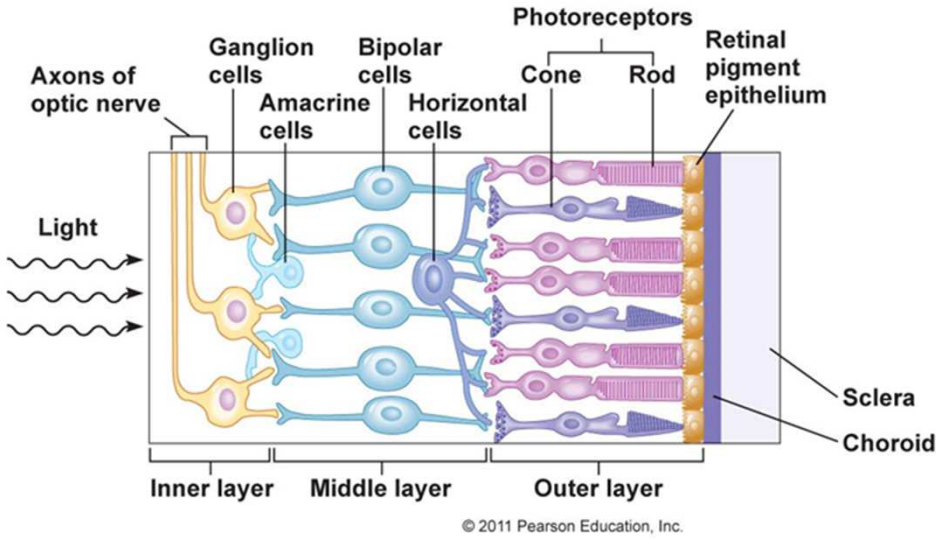
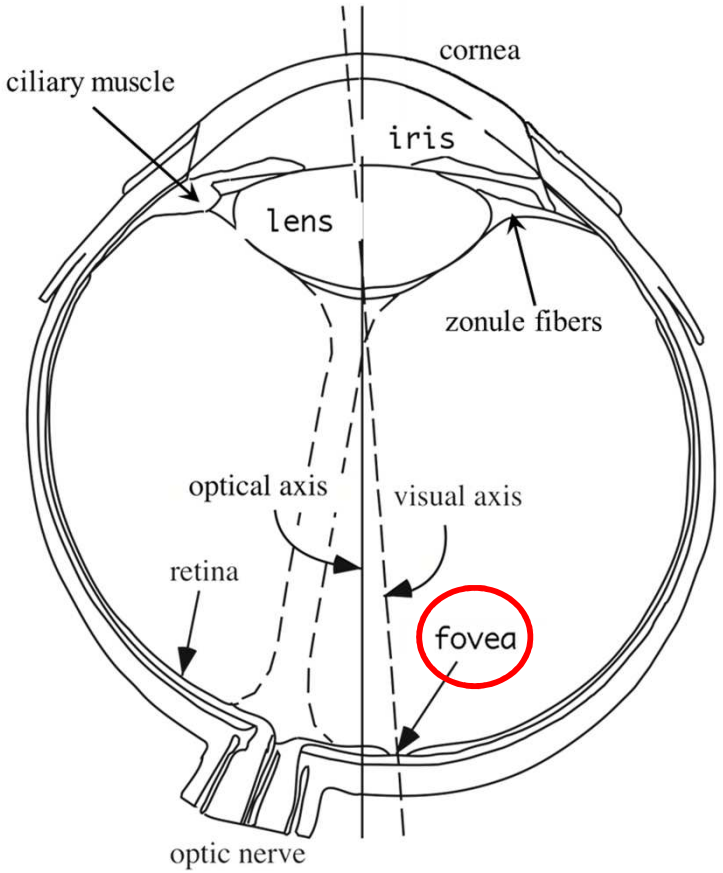
THE HUMAN VISUAL SYSTEM

- eye lens
- photosensitive receptors in fovea
  - fovea with cones (where you look at)
  - wide area: rods
- axons: transfer the information
- blind spot



Right eye



130 million photoreceptors
1 million nerve fibres

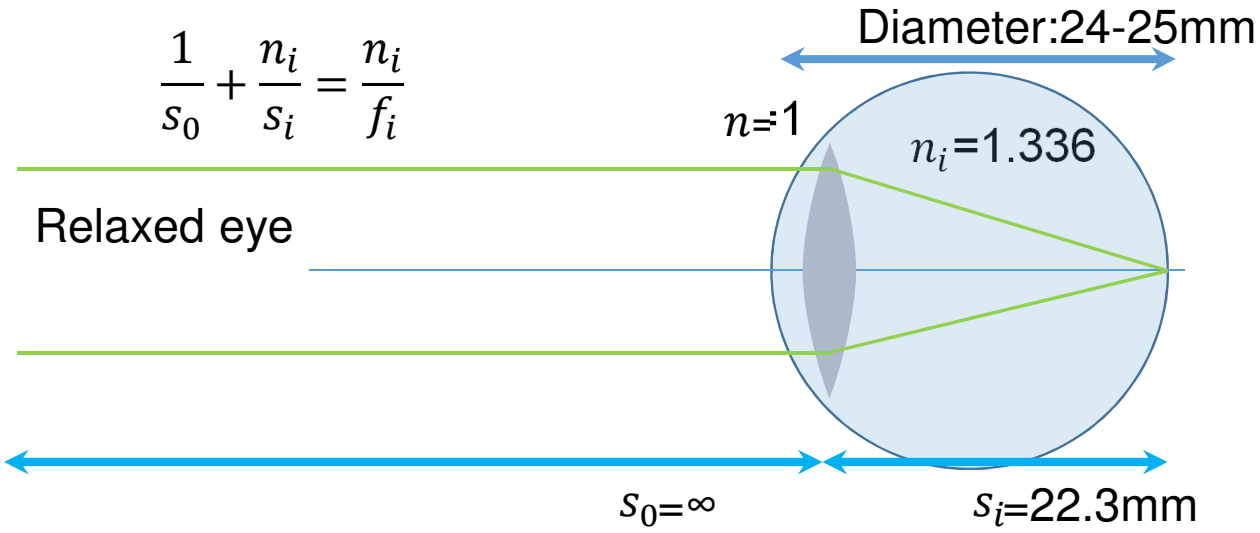
THE HUMAN VISUAL SYSTEM

Close left eye and focus on the cross.
At a certain distance you will not see the black dot

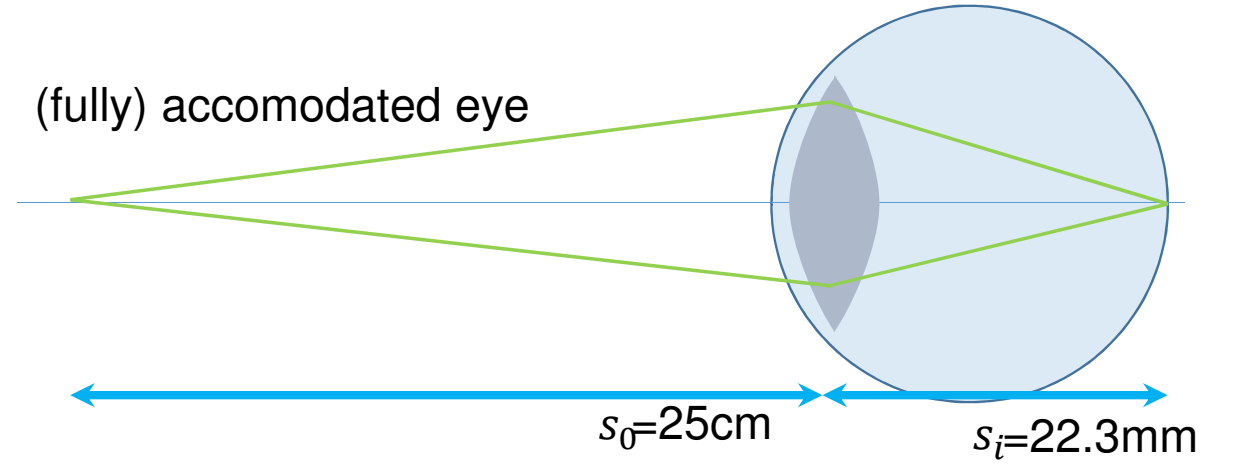
Blind spot due to optic nerve

THE HUMAN VISUAL SYSTEM

$$\frac{1}{s_0} + \frac{n_i}{s_i} = \frac{n_i}{f_i}$$



Focal length f_i=22.3 mm



Focal length f_i=20.9 mm

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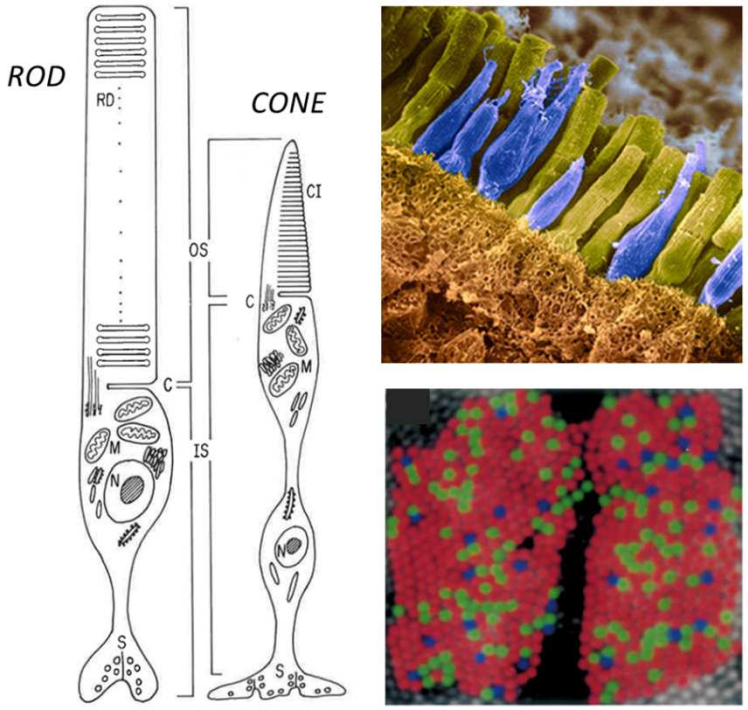
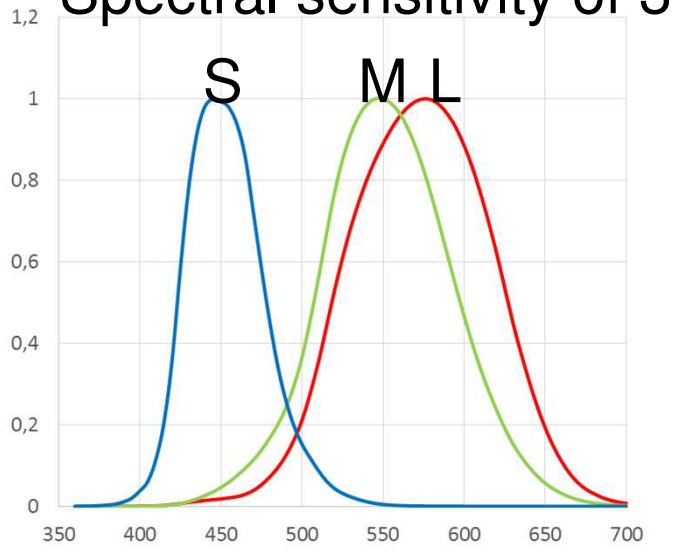
THE HUMAN VISUAL SYSTEM

Color perception: 3 cone fundamentals (absorption by molecules)

L (60%), M (30%) and S (10%) cones



Spectral sensitivity of 3 cones



λ (nm)

S cones practically do not contribute to brightness, eye sensitivity: V(λ) =a(1.5L+M))

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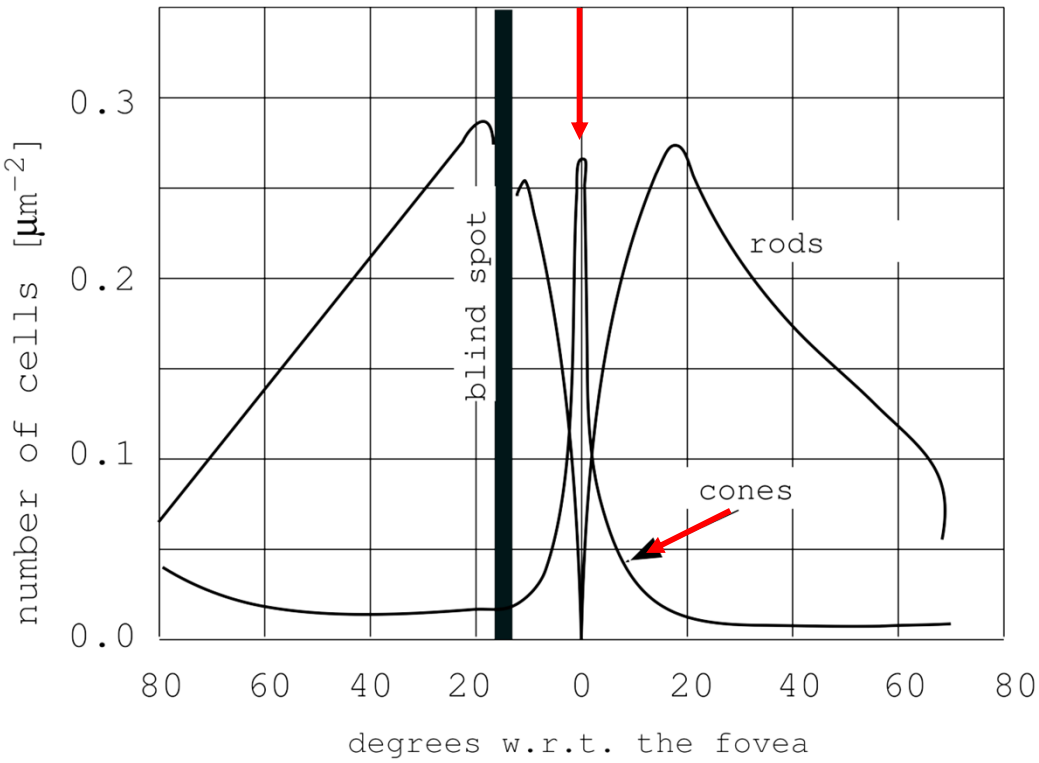
Cone & rod density

- Cones are most abundant in an area of ±2 degrees (the fovea)
- The resolving power of the rods is much smaller, but they are more sensitive.



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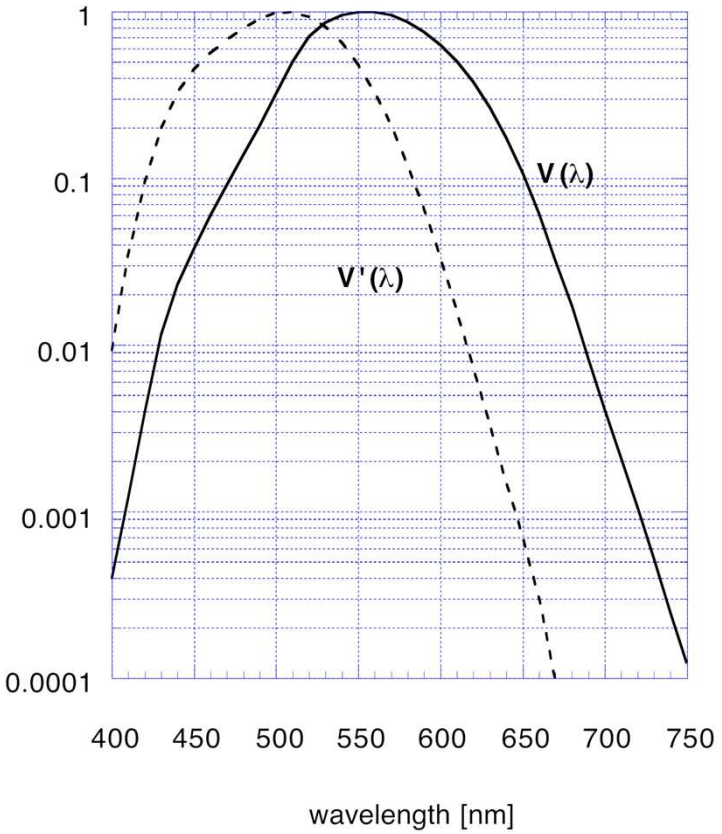
eye sensitivity curve



The spectral density $X_{e,\lambda}(\lambda)$ is weighted by the sensitivity $V(\lambda)$ of human vision

brightness:

$$X_v = K_m \int V(\lambda) X_{e,\lambda}(\lambda) d\lambda$$

K_m=683 lm/W

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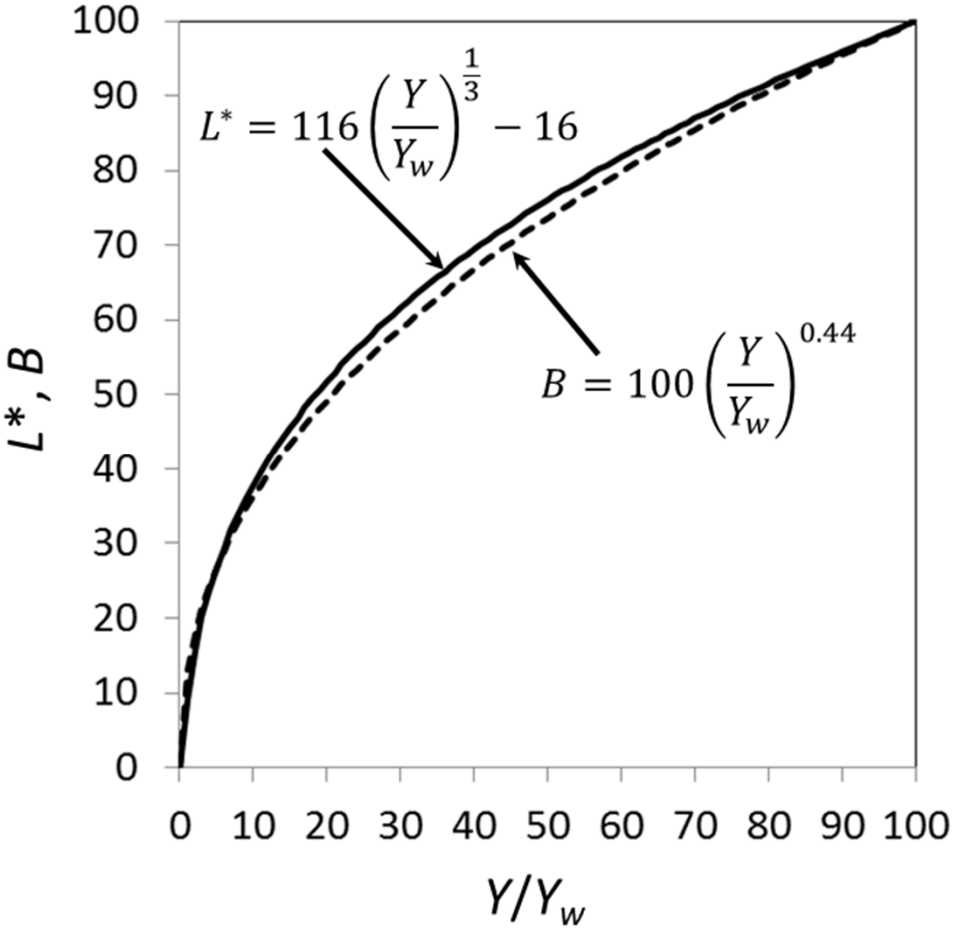
Nonlinear
brightness perception



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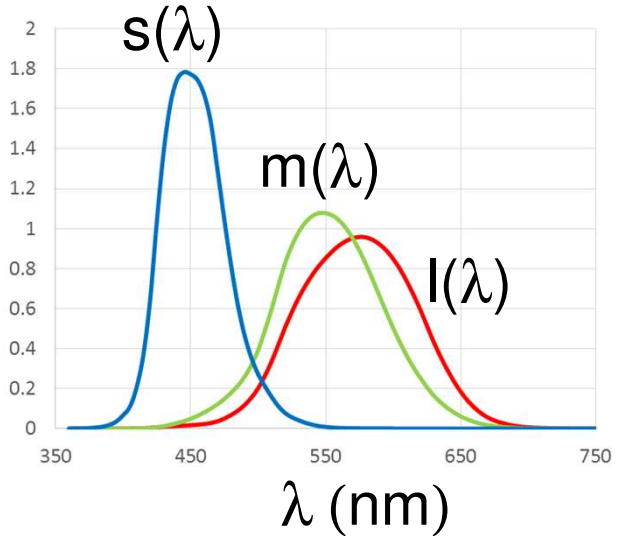
cone responses yields 3 numbers

$$L = \int St(\lambda) l(\lambda) d\lambda$$

$$M = \int St(\lambda) m(\lambda) d\lambda$$

$$S = \int St(\lambda) s(\lambda) d\lambda$$

sensitivity of the three cones



equal energy white: L=M=S

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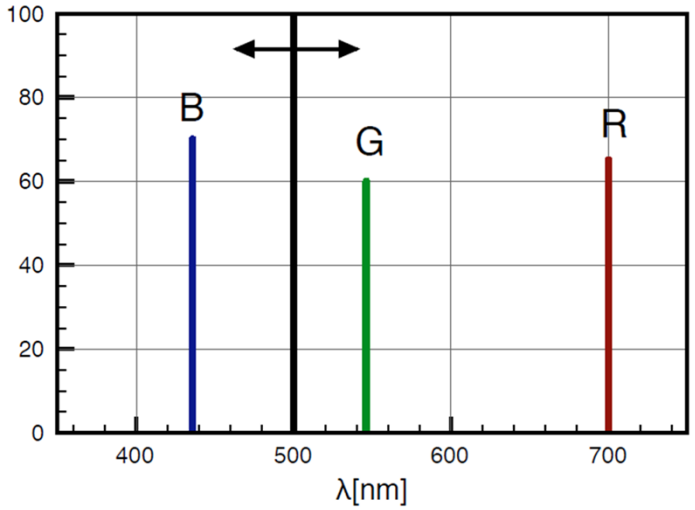
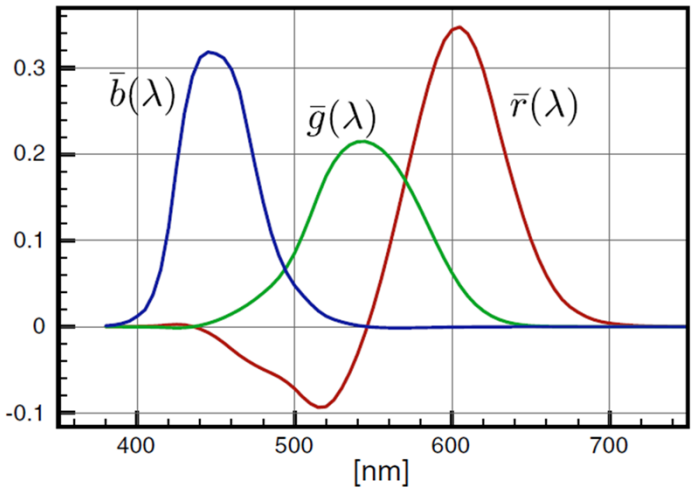
Color matching

3 Primaries: 700 nm (red), 546.1 nm (green) and 435.8 nm (blue)

any monochromatic color can be made by combining 3 primaries





color matching functions:
used to match monochromatic colors

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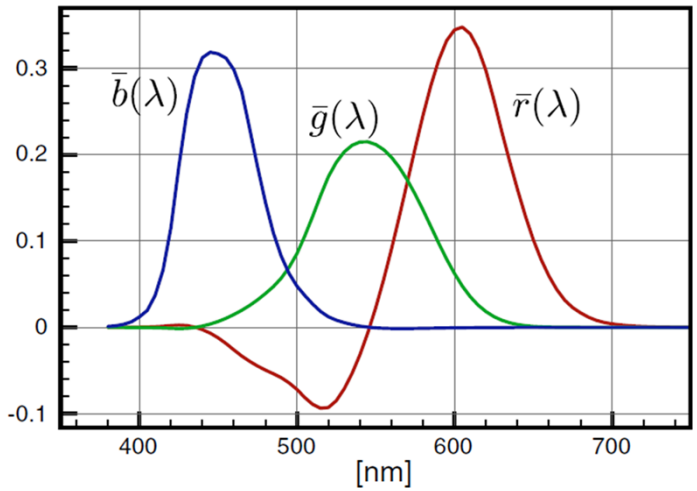
CIE 1931 2° standard observer

given a spectrum St(λ), the RGB coordinates can be calculated



$$\begin{cases} R = \int St(\lambda)\bar{r}(\lambda)d\lambda \\ G = \int St(\lambda)\bar{g}(\lambda)d\lambda \\ B = \int St(\lambda)\bar{b}(\lambda)d\lambda \end{cases}$$

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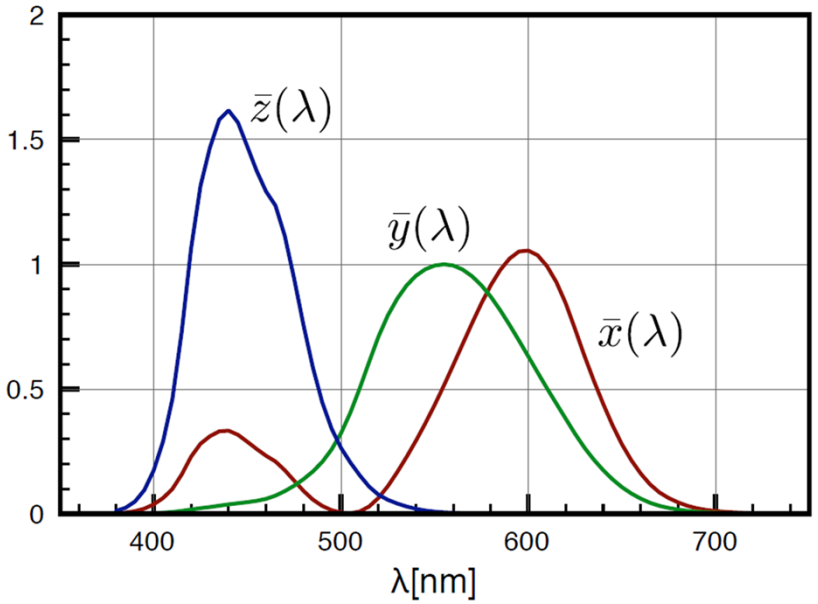
CIE 1931 2° XYZ color system (only positive coordinates)



$$\begin{cases} X = 683\ \mathrm{lm/W} \int St(\lambda)\bar{x}(\lambda)d\lambda \\ Y = 683\ \mathrm{lm/W} \int St(\lambda)\bar{y}(\lambda)d\lambda \\ Z = 683\ \mathrm{lm/W} \int St(\lambda)\bar{z}(\lambda)d\lambda \end{cases}$$

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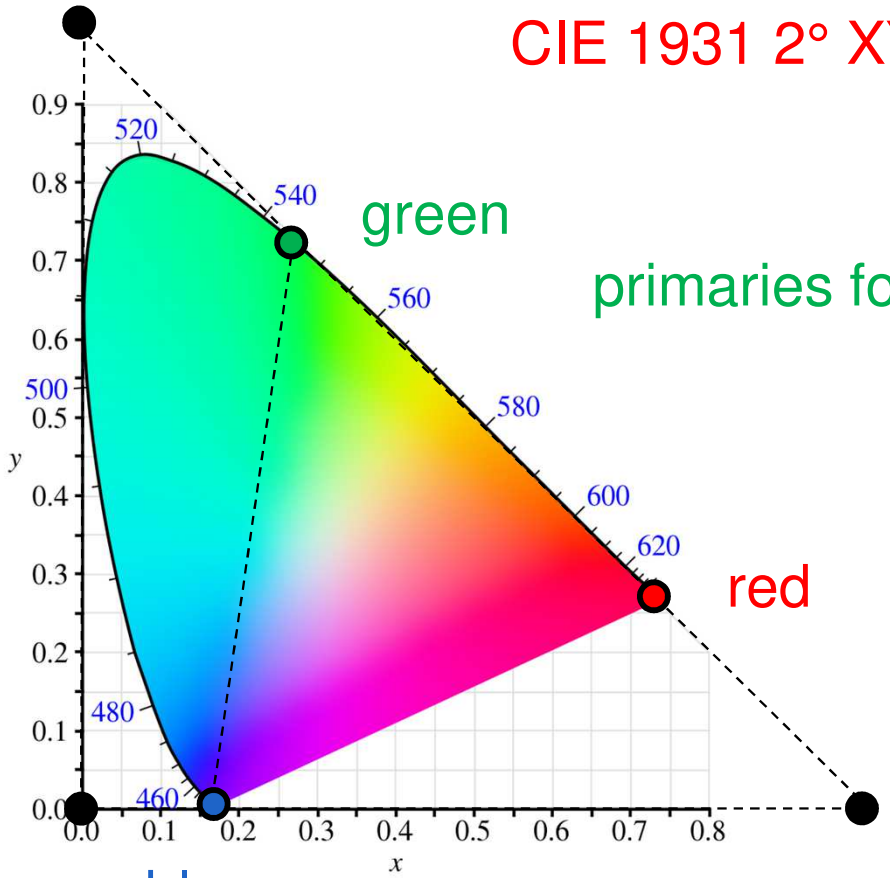
primaries for XYZ

$$y = \frac{Y}{X + Y + Z}$$



CIE 1931 2° XYZ color system

green

primaries for RGB

red

blue

$$x = \frac{X}{X + Y + Z}$$

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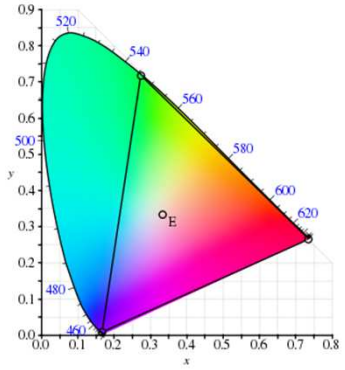
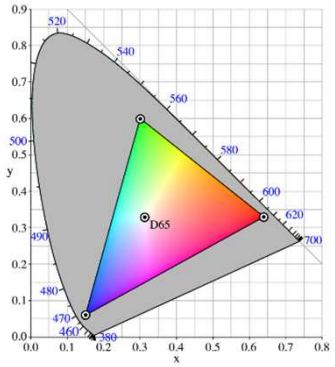
Where are the color models used?

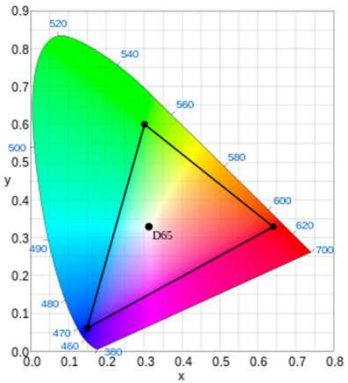
CIE RGB: 3 original primaries



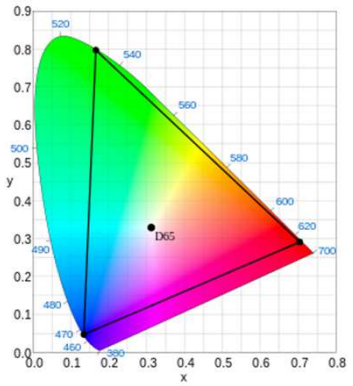


sRGB: most commonly used color model for monitors, printers, internet (standard by HP, Microsoft), white D65

Rec. 709: color gamut for HDTV



Rec. 2020: proposed color gamut



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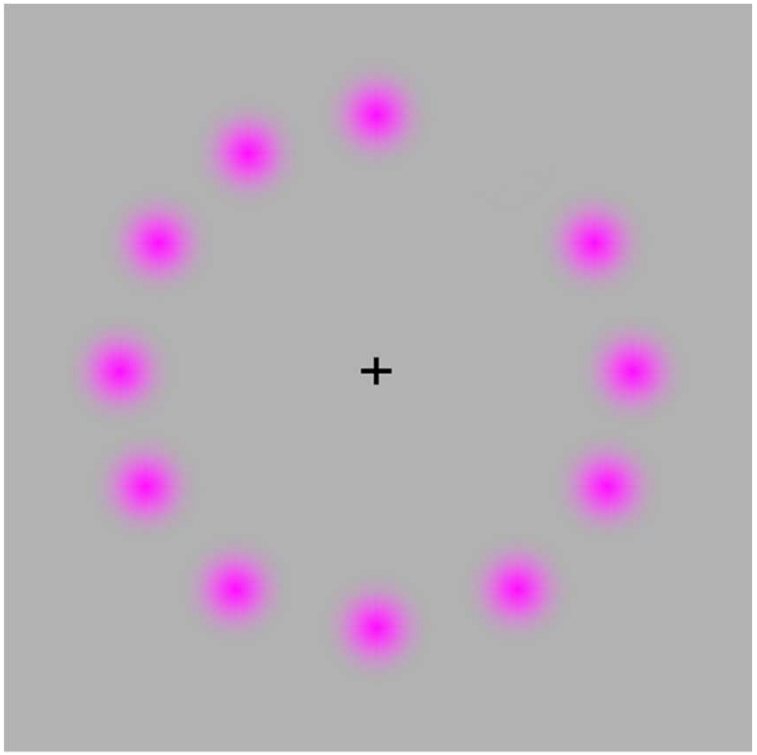
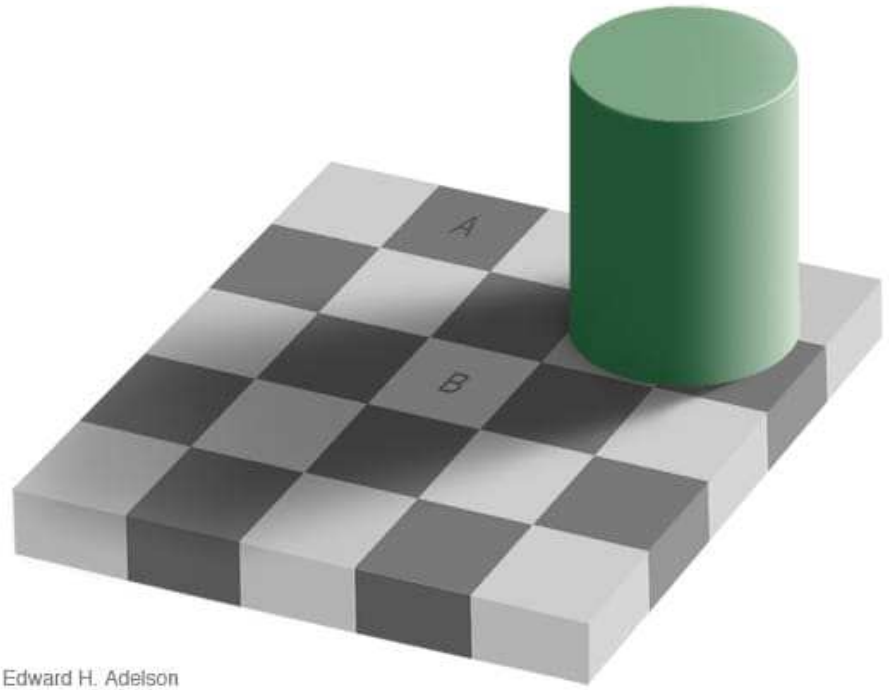
Chromatic adaptation



Interpretation



Edward H. Adelson

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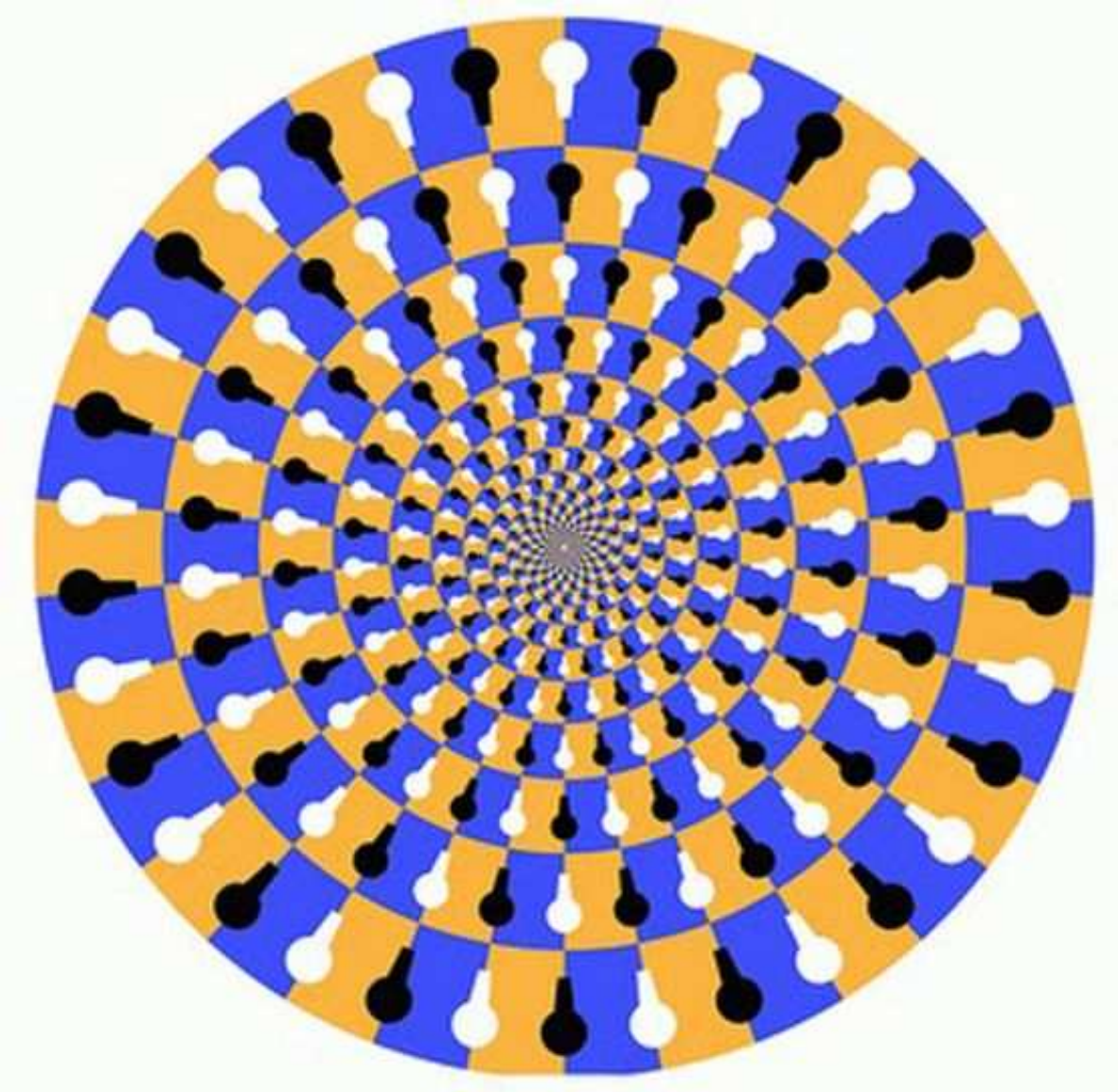

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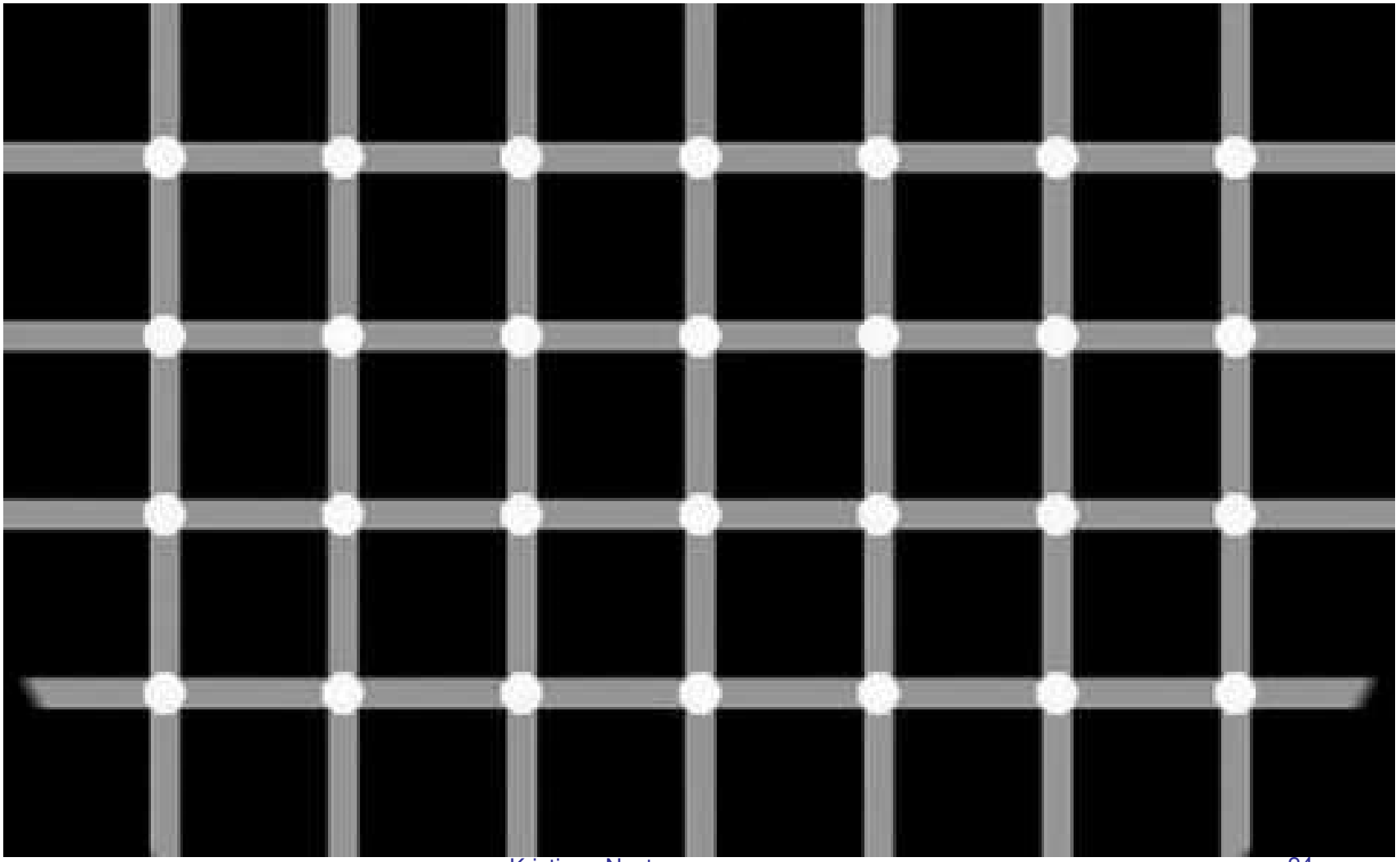

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DISPLAY CHARACTERISTICS

Basic optical display characteristics:

- **Resolution**
  HDTV: 1920×1080 pixels
  2 Mpixels per frame, 25 Hz frame rate, 52 MHz pixel rate,
  8 bits/color, 1.24 Gbit/s uncompressed, 8-15 Mbit/s compressed
- **Luminance**
  TV 500 Cd/m^2
  inhomogeneous encoding (more dark levels)
- **Contrast**
  C=(bright-dark)/dark ~1000
  contrast in a bright environment is much less…

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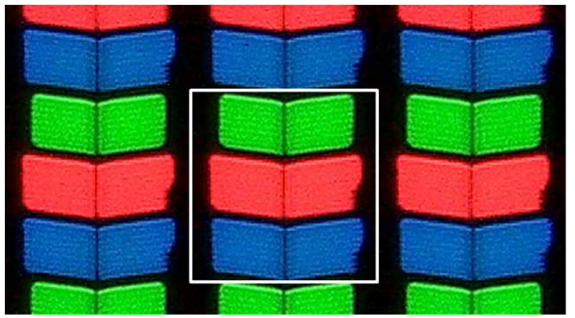
DISPLAY CHARACTERISTICS

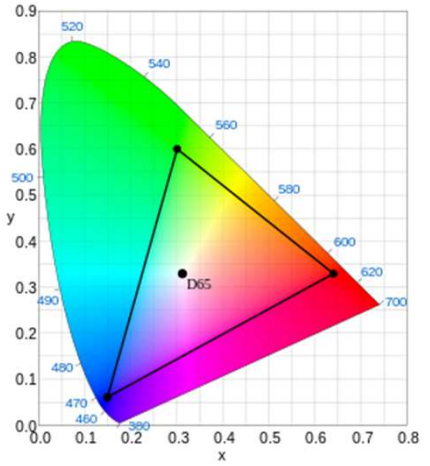
Luminance and color based on red green and blue pixels

fill-factor (~60%)
subpixel architecture
AMLCD display - IPS
(here Apple iPad 2)



Color gamut

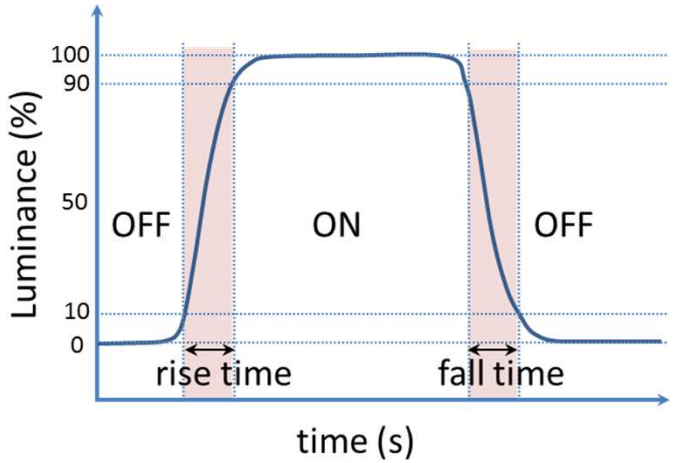
- Area in the color triangle of possible colors
- determined by the RGB pixels



DISPLAY CHARACTERISTICS

Frame rate

- 60 Hz or 120 Hz for television
- movies @24 fps, displayed at the double frequency
  (cinema:48Hz)
- Current LCD and OLED TV's display at 120Hz
- Response time: 20 ms is fine



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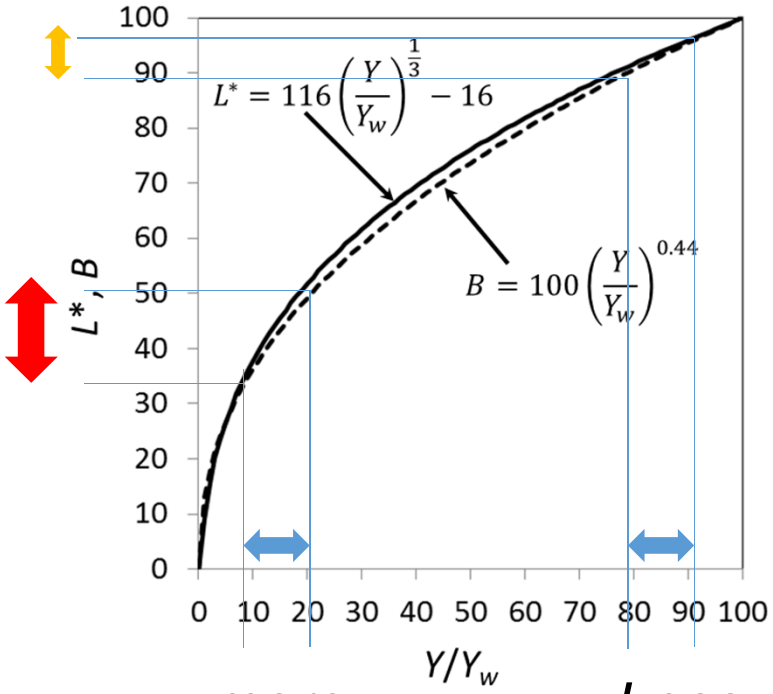
DISPLAY CHARACTERISTICS

gamma correction

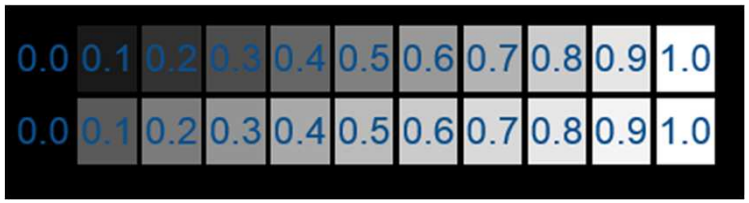
- optimize the usage of bits
  $\gamma \approx 0.44$
- the inverse operation (decoding) with
  $\gamma \approx 0.22$



more sensitive→ assign more bits

Less sensitive → assign less bits

encoded

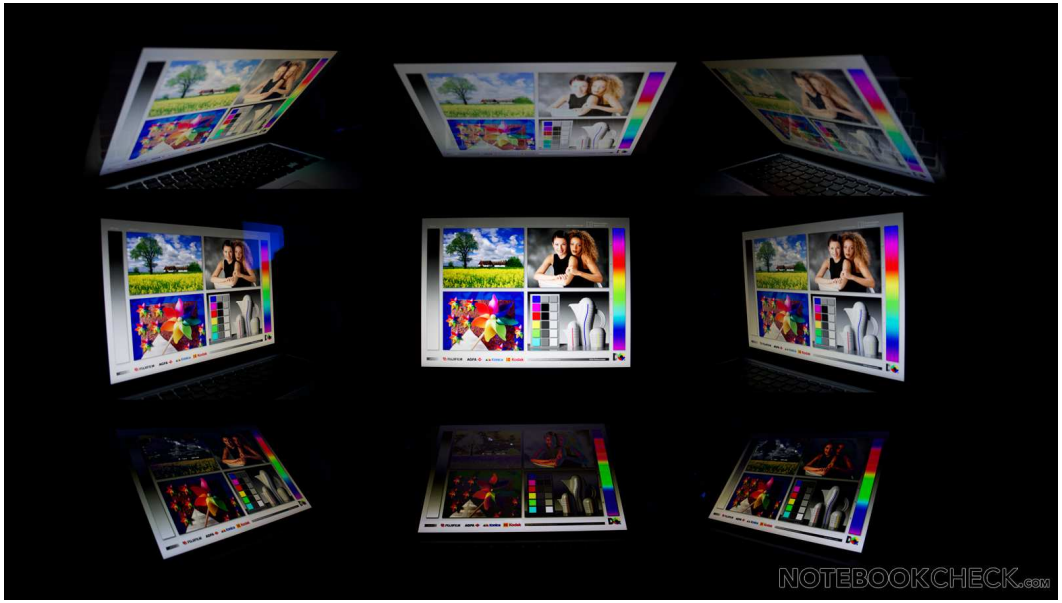


original (linear luminance)

DISPLAY CHARACTERISTICS

Viewing angle

- angle w.r.t. display normal at which the contrast ratio decreases to a fixed value (e.g. 10:1)
- 70° for AMLCD, IPS>VA LED



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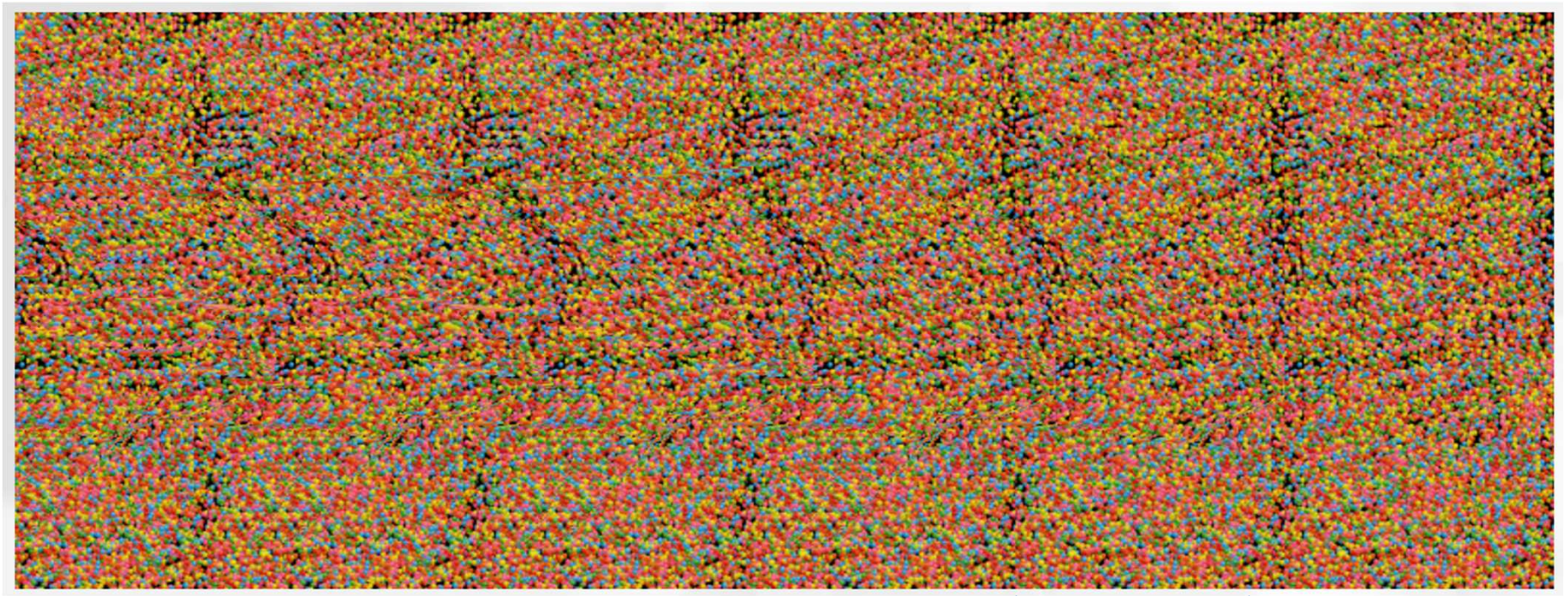
THE HUMAN VISUAL SYSTEM

autostereogram: find the hidden animal…



only visible when this distance

is smaller than 65 mm (distance between the eyes)