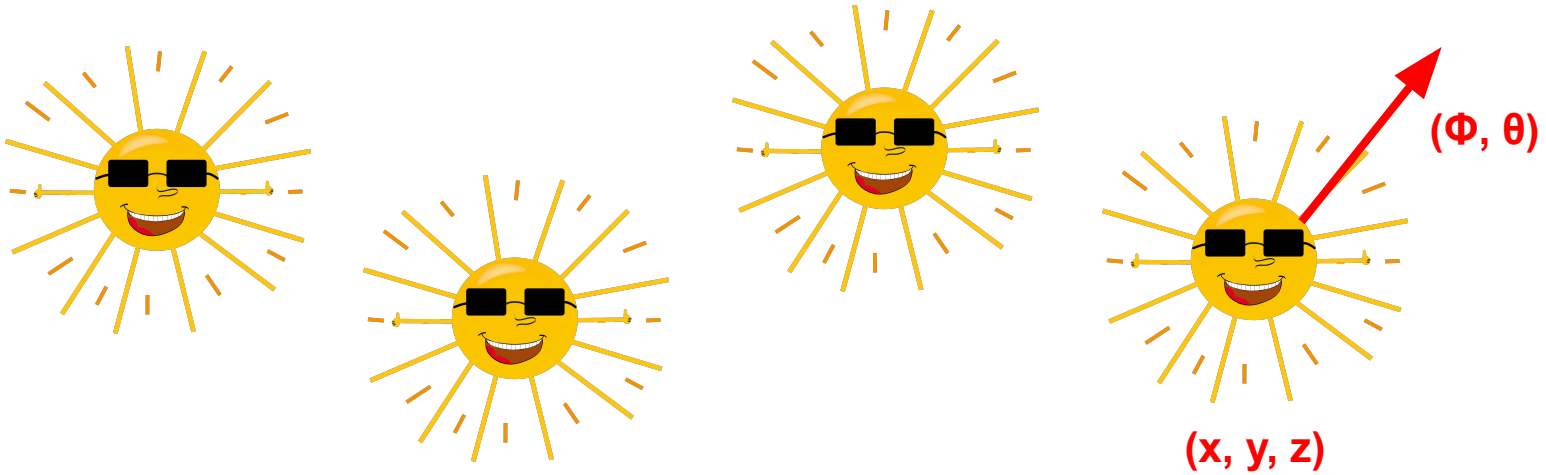
Perception

Dr Fangcheng Zhong

Outline

- XR visual requirements
  - Geometric considerations
    - FoV, acuity, depth cues
  - Spectral considerations
    - colour vision, luminance, contrast
  - Temporal considerations
    - motion artefacts, persistence

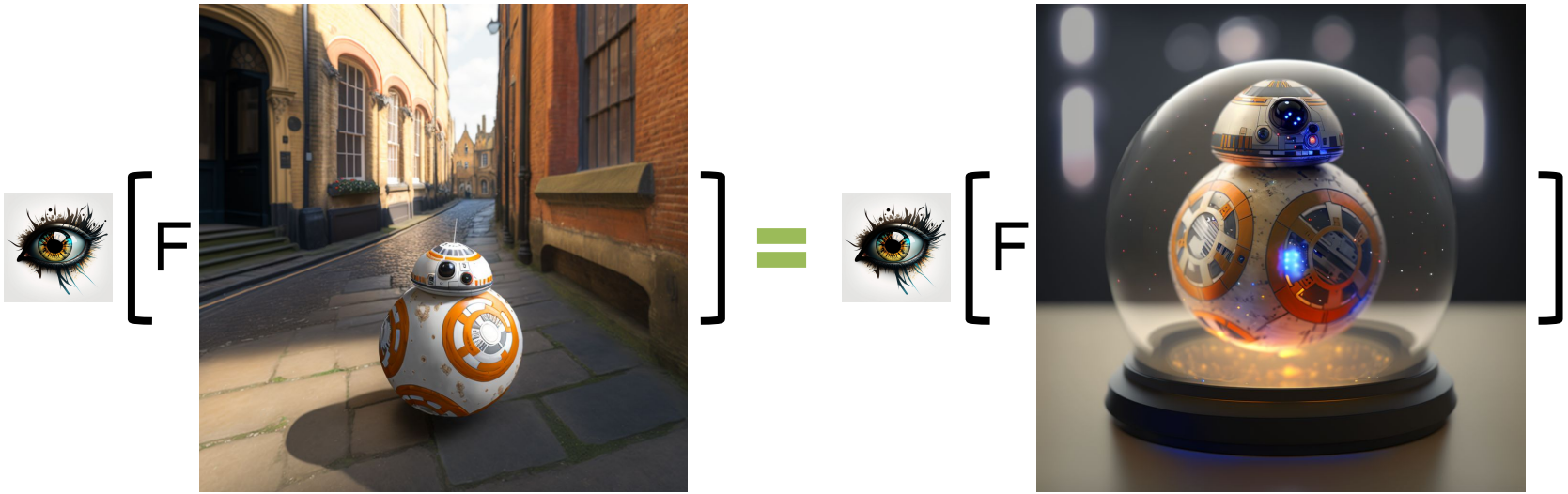
Light Fields



$$\Phi = F(x, y, z, \theta, \varphi, \lambda, t)$$

spectral radiance wavelength time

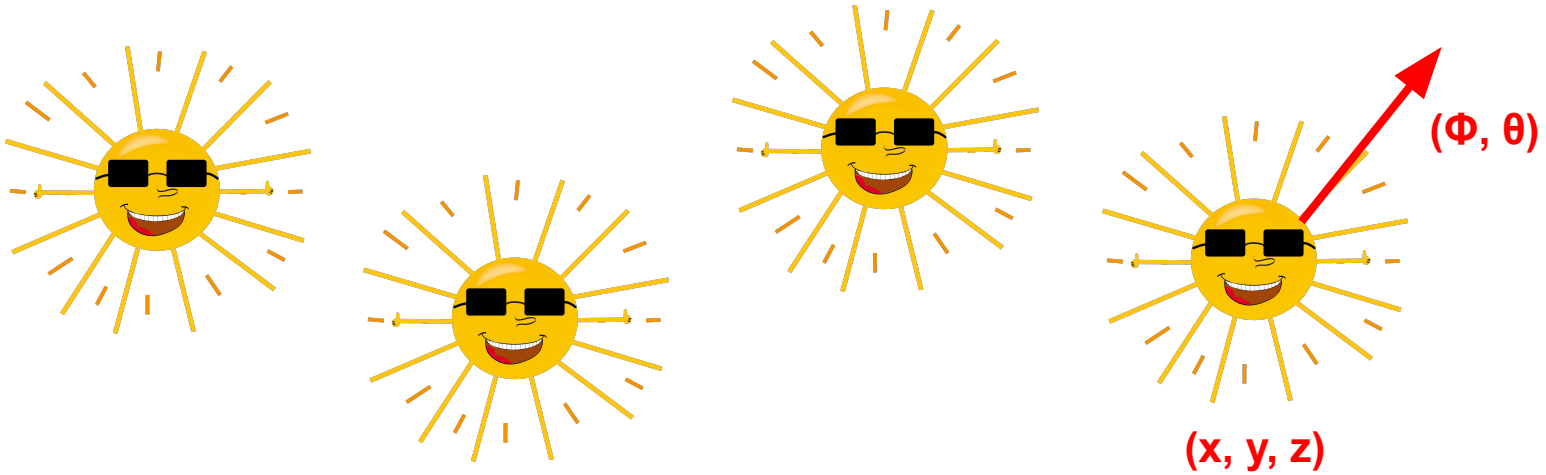
Perceptual Realism



real

virtual

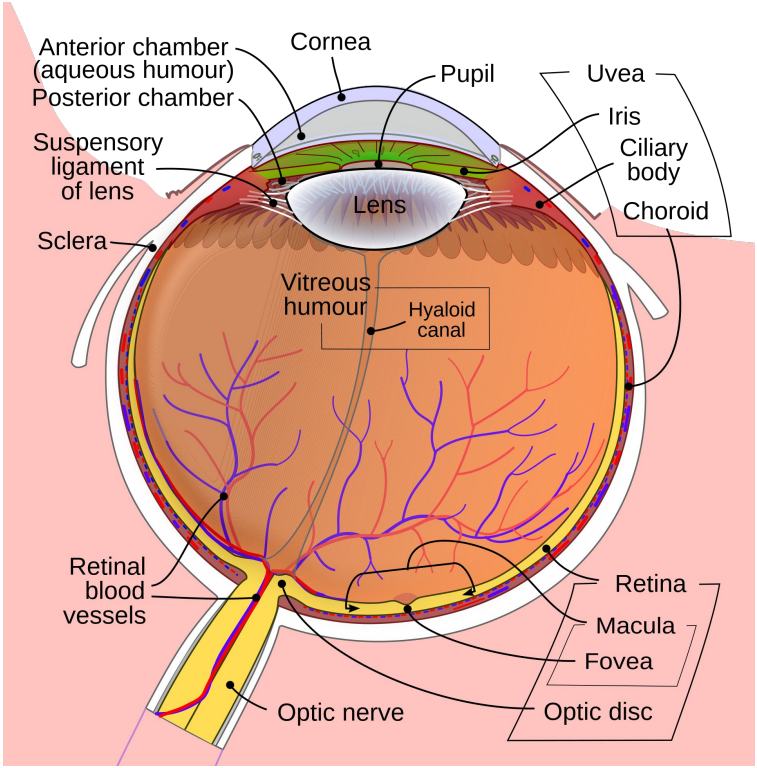
Light Field Perception



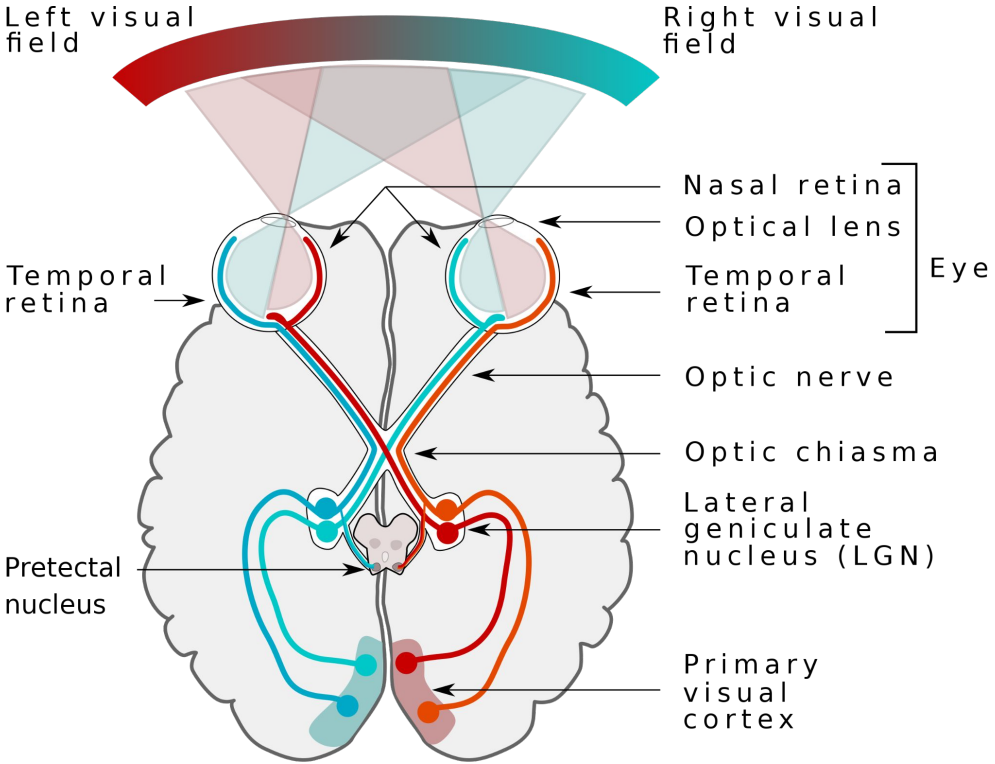
$$\Phi = F(x, y, z, \theta, \varphi, \lambda, t)$$

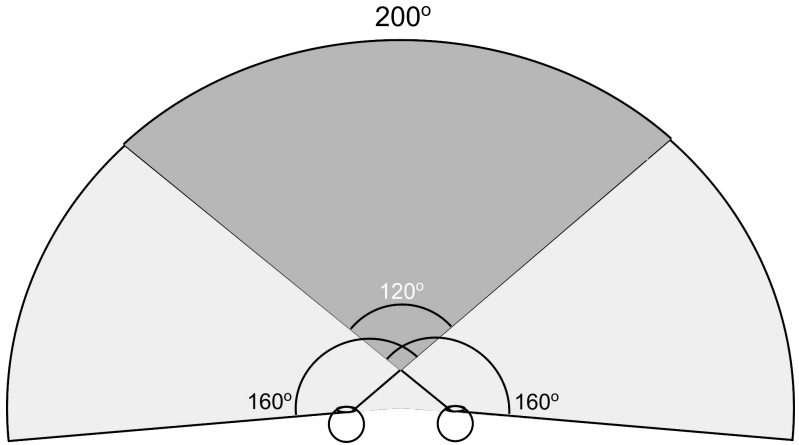
geometric spectral temporal

Human Visual System



Binocular FoV



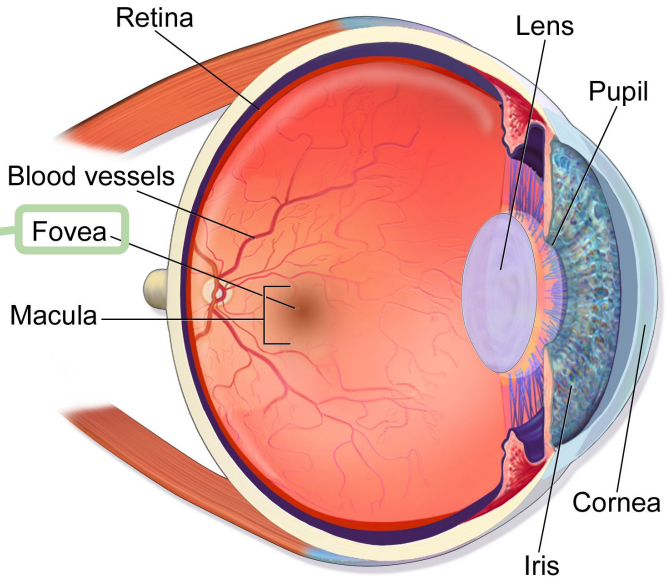


Acuity

- Ability to distinguish small details on the retina

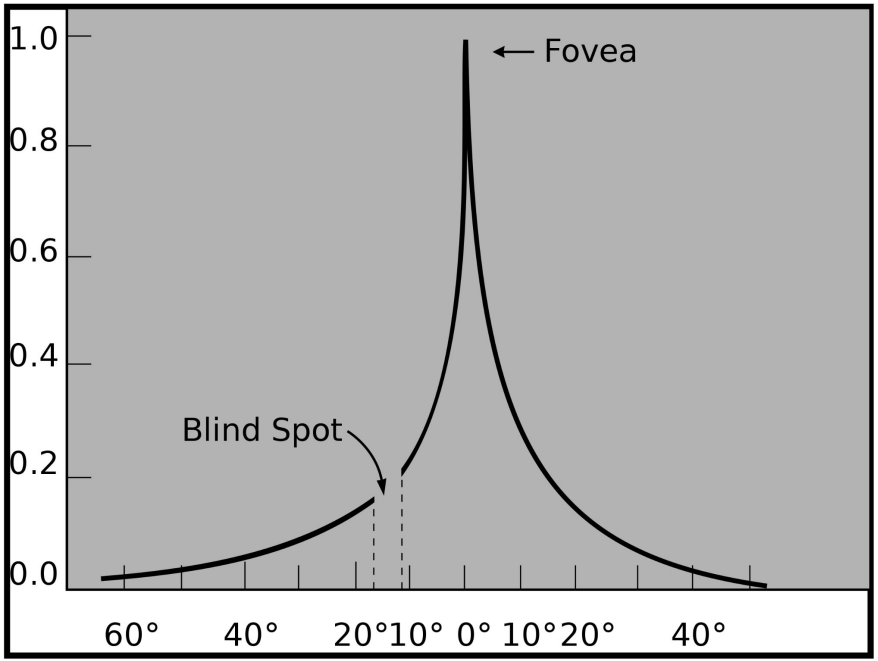
peak acuity

approximately
120 cycles per degree (cpd)
240 pixels per degree (pdd)

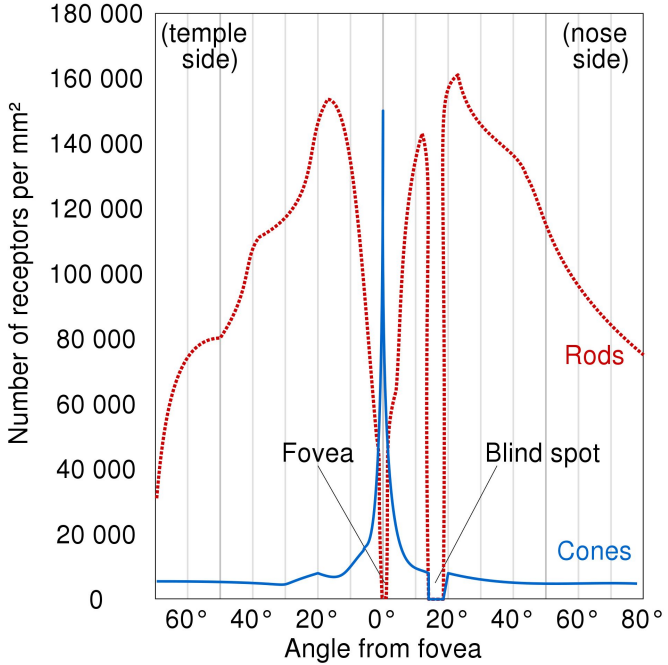


Eye Anatomy

Acuity



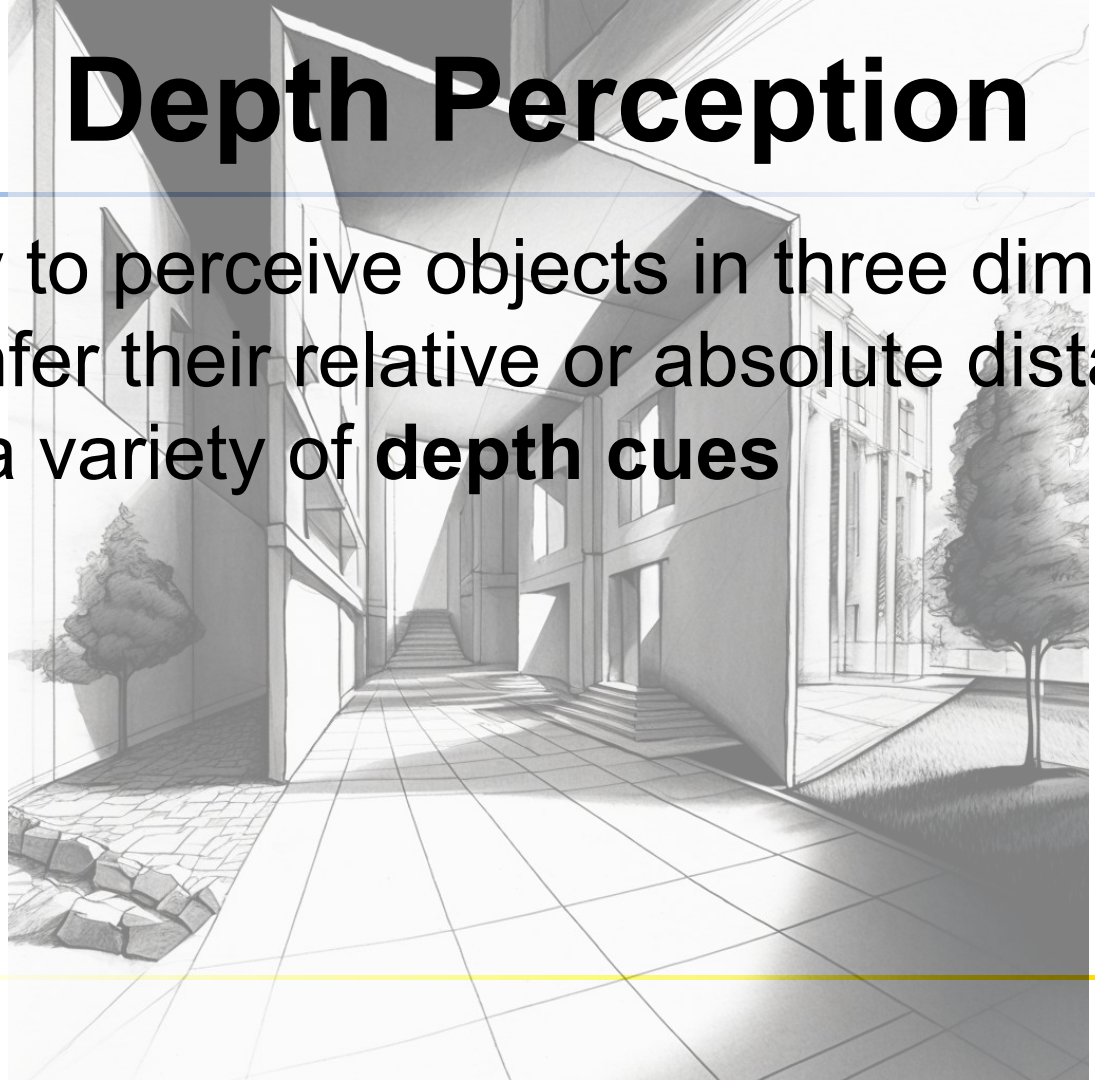
relative acuity of the left human eye in degrees from the fovea



distribution of photoreceptors

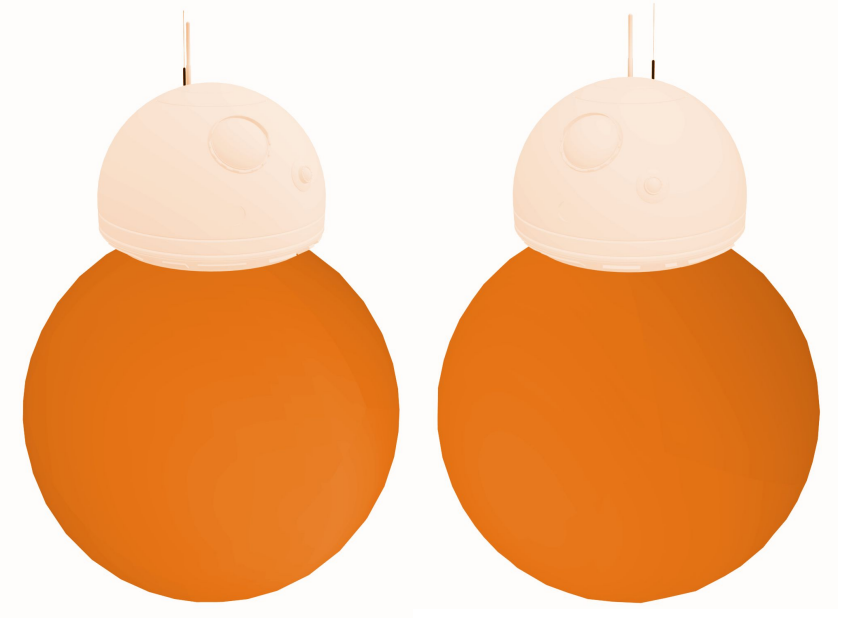
Depth Perception

- Ability to perceive objects in three dimensions and infer their relative or absolute distances from a variety of **depth cues**



Depth Perception

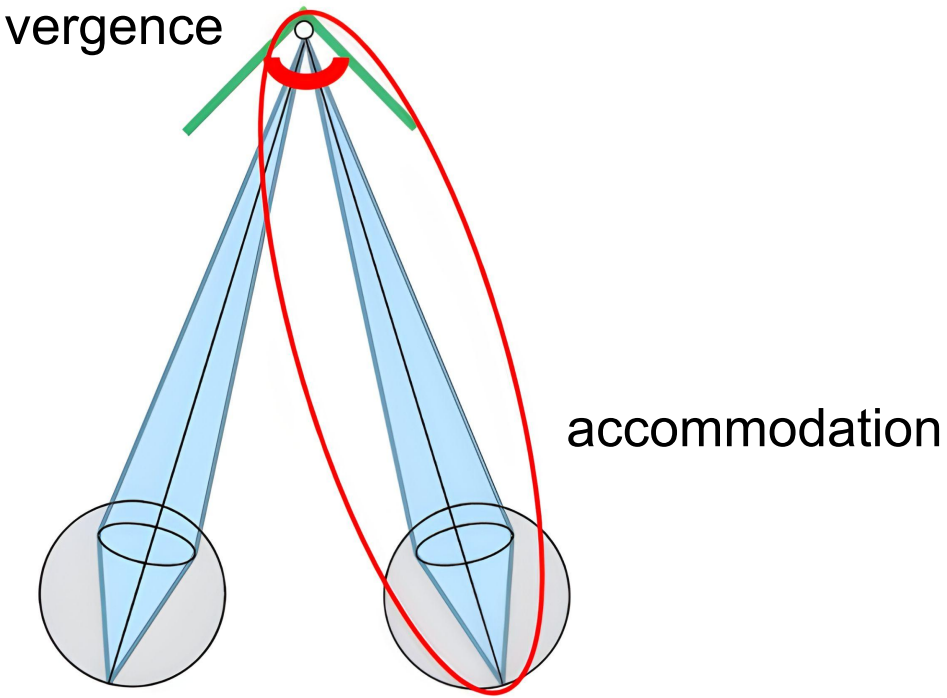
binocular disparity



left view

right view

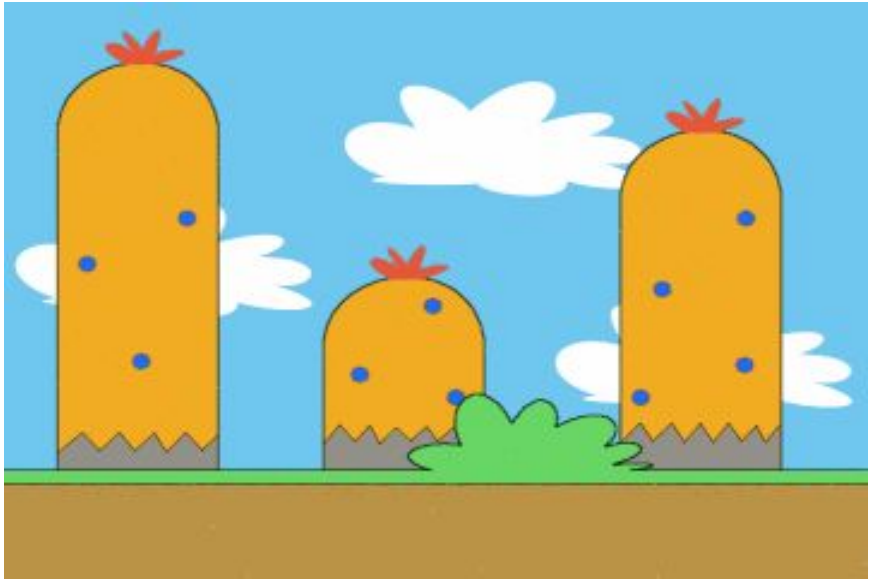
Depth Perception



Depth Perception

Depth Perception

parallax

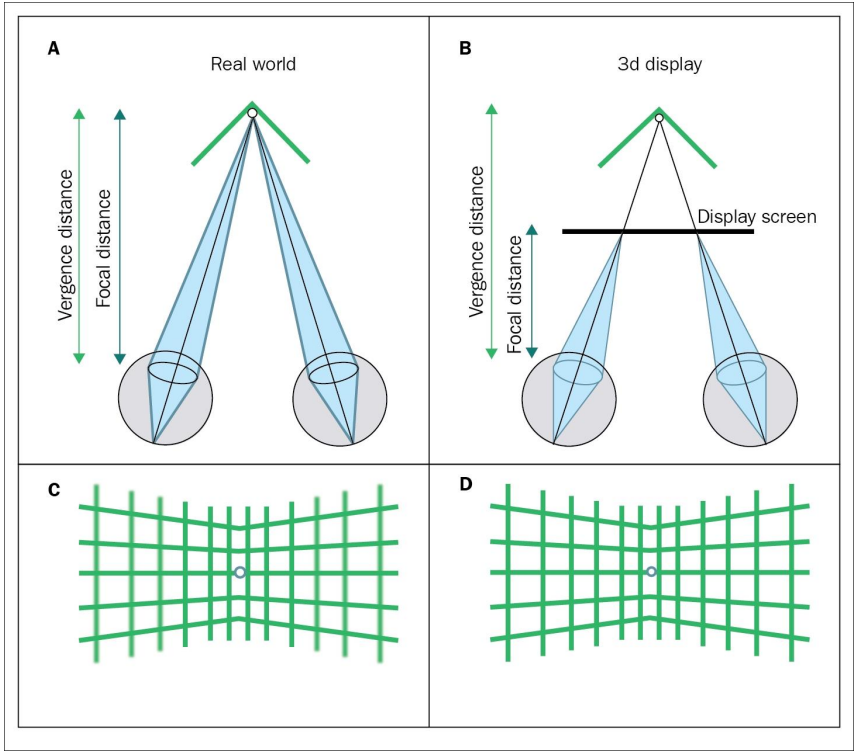


Depth Perception

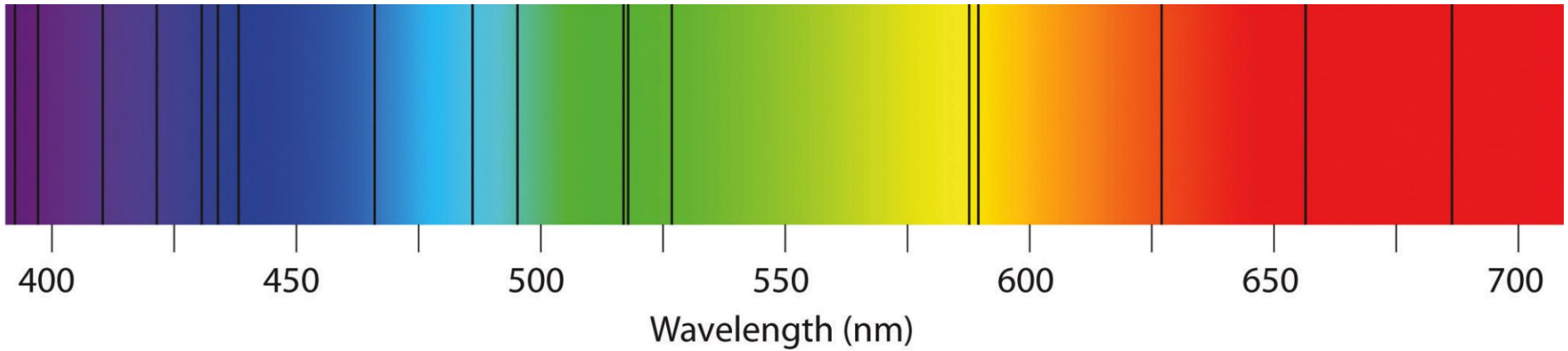
- Depth cues are the deciding factor differentiating 3D displays from 2D ones

	Binocular cues	**Monocular cues**
Pictorial cues	disparity	defocus blur, parallax, perspective, relative size, occlusion, shading
Oculomotor cues	vergence	accommodation

Vergence-Accommodation Conflits

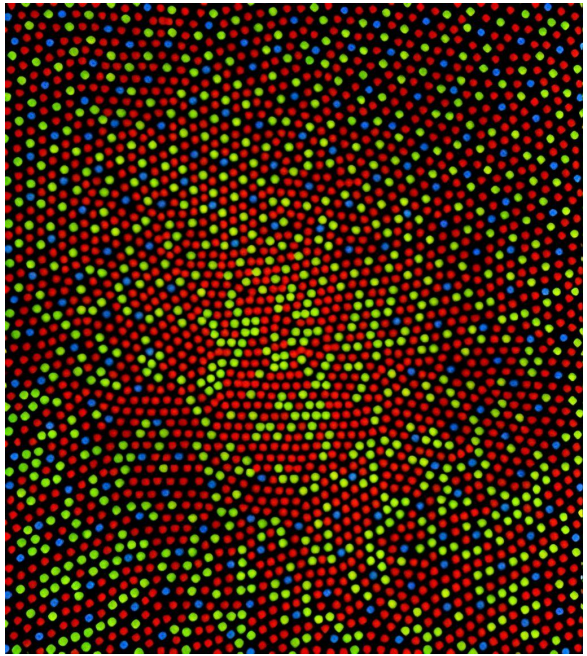


Colour Vision

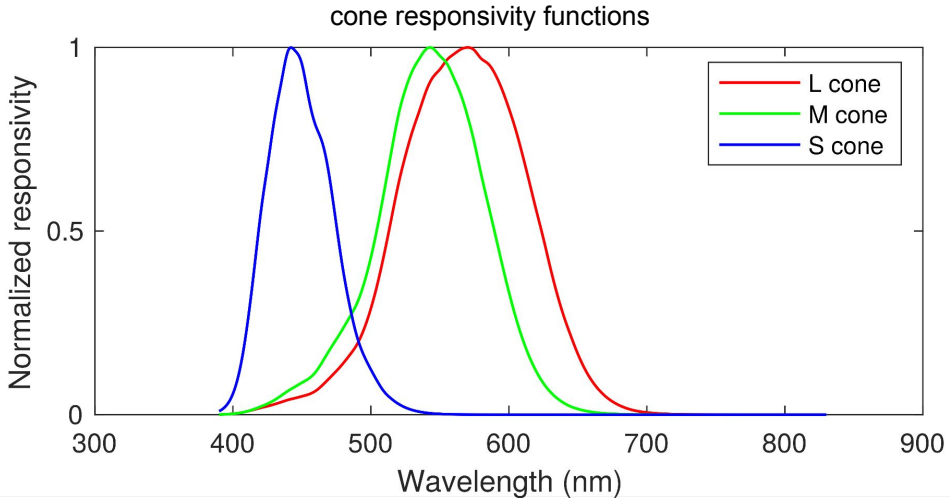


visible spectrum

Colour Vision



distribution of cone cells in the fovea



spectral radiance

$$\mathbf{L} = \int_{\lambda} \Phi(\lambda) L(\lambda)\, d\lambda\,,$$

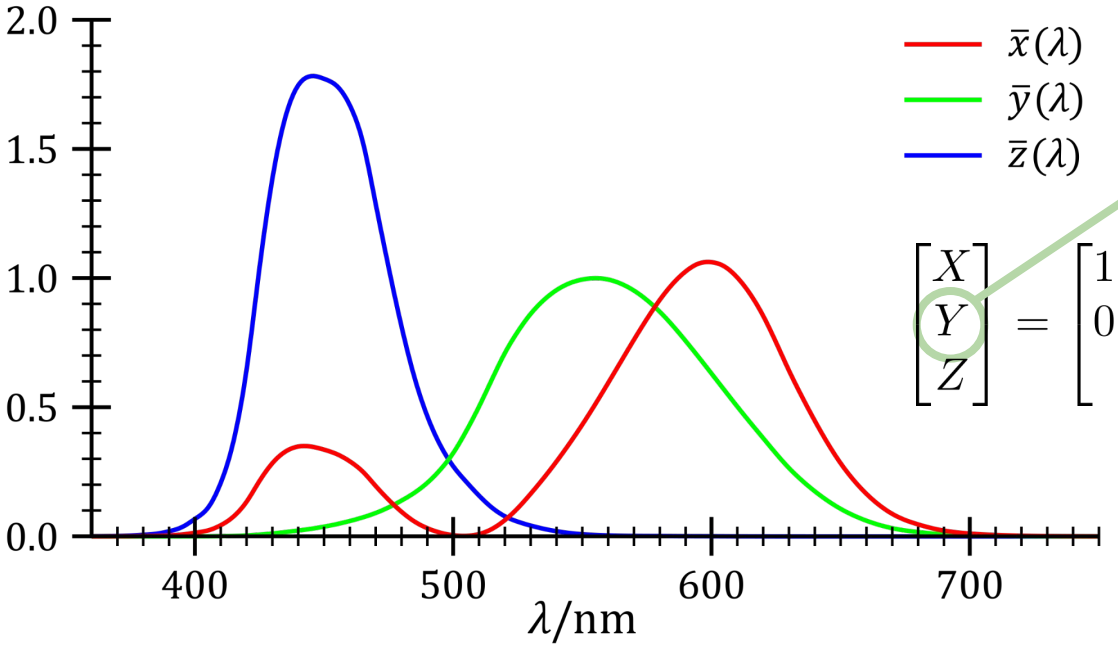
$$\mathbf{M} = \int_{\lambda} \Phi(\lambda) M(\lambda)\, d\lambda\,,$$

$$\mathbf{S} = \int_{\lambda} \Phi(\lambda) S(\lambda)\, d\lambda\,,$$

Colour Vision

- **Luminance** — a photometric measure of the intensity
- **Chromaticity** — the relative spectral power distribution of the light waves regardless of its absolute intensities

Colour Vision



relative luminance

$$\begin{bmatrix} X \\ Y \\ Z \end{bmatrix} = \begin{bmatrix} 1.9102 & -1.1122 & 0.2006 \\ 0.3709 & 0.6291 & -0.0003 \\ 0 & 0 & 1.0000 \end{bmatrix} \begin{bmatrix} L \\ M \\ S \end{bmatrix}$$

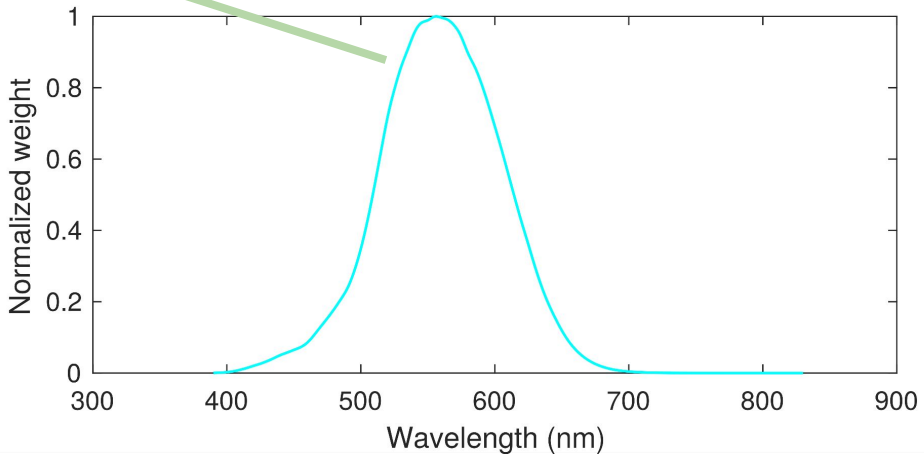
CIE XYZ standard observer color matching functions

Luminance

photopic luminous efficiency function

$$Y = 683.002\ lm/W \int_{\lambda} \Phi(\lambda)\bar{y}(\lambda)\, d\lambda$$

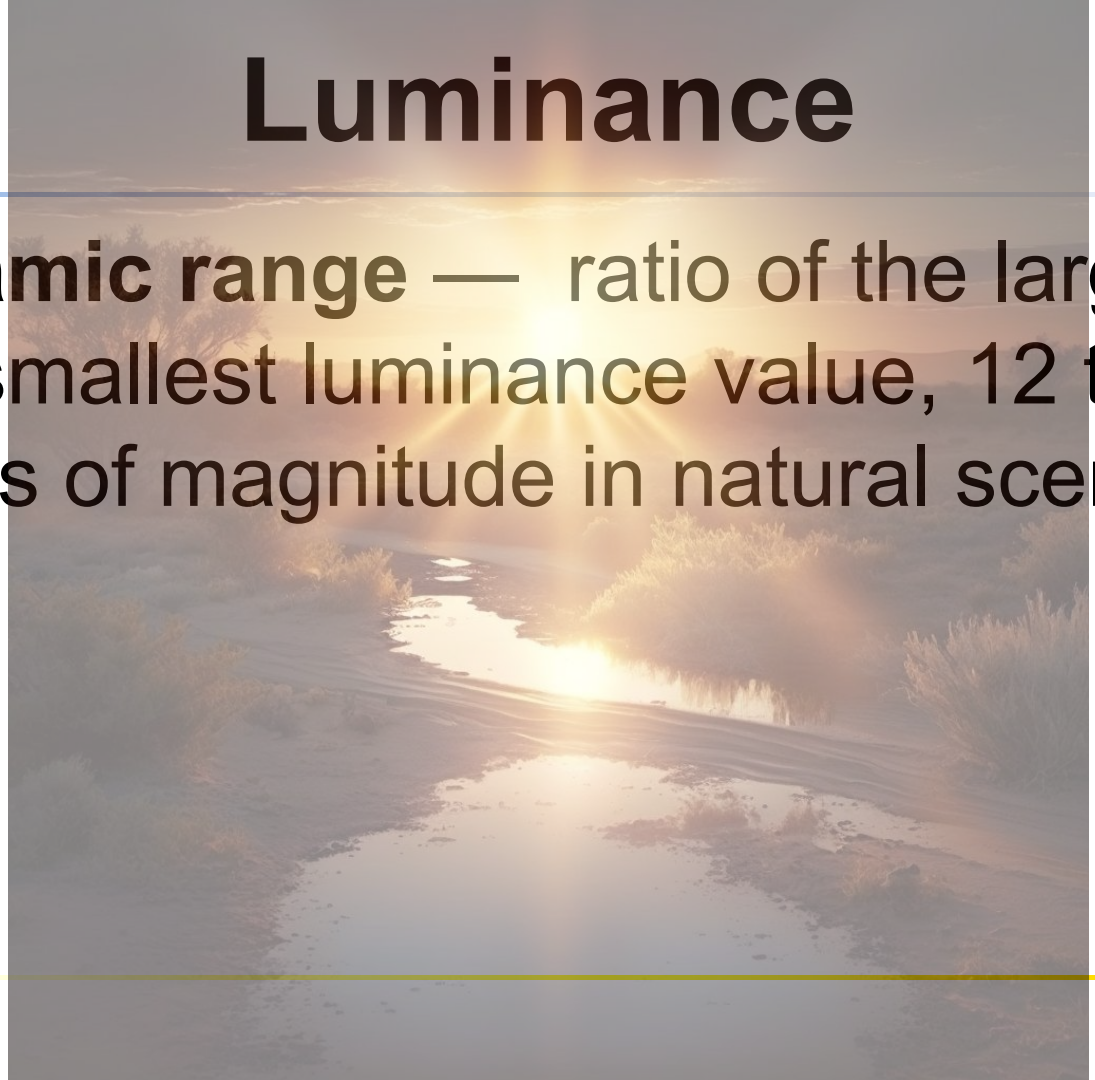
luminance



- The photopic luminous efficiency function is a weighted sum of cone responsivity functions according to their relative population on the retina

Luminance

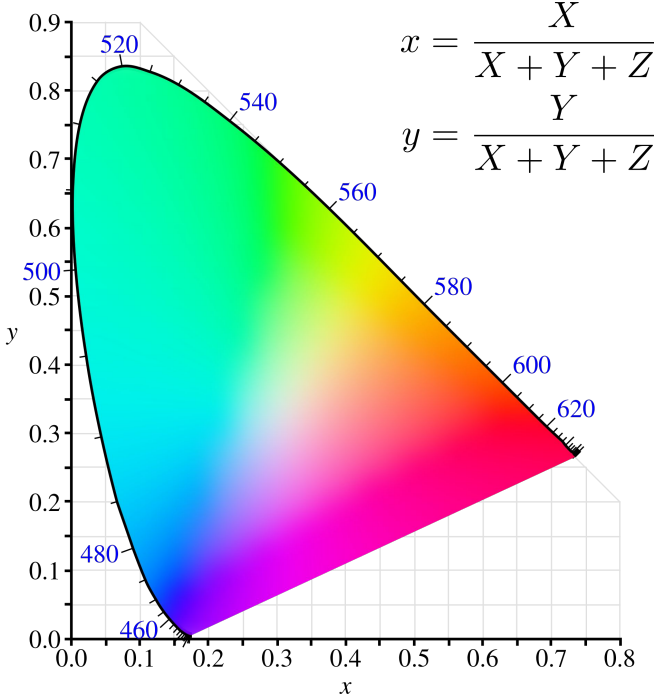
- **Dynamic range** — ratio of the largest and smallest luminance value, 12 to 14 orders of magnitude in natural scenes

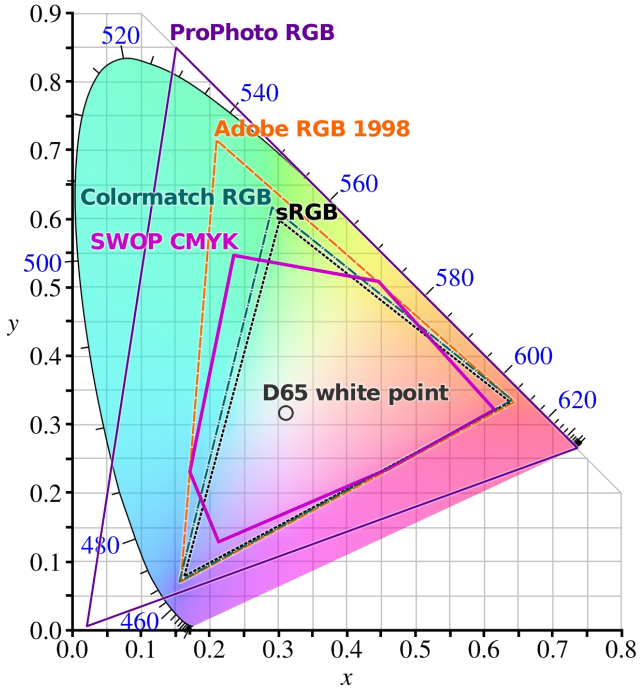


Chromaticity

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

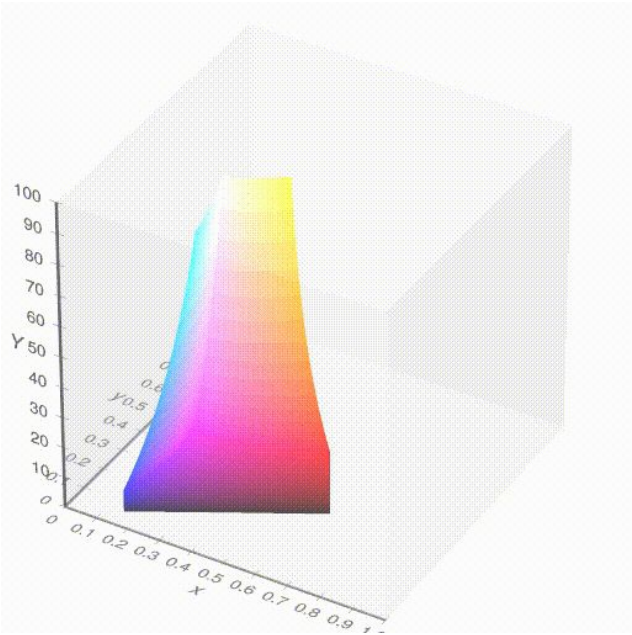
$$y = \frac{Y}{X+Y+Z}$$



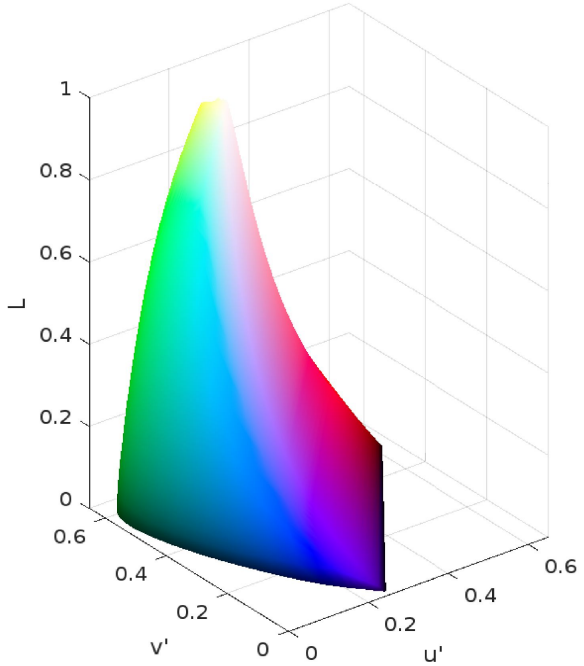


chromaticity diagram

Colour Gamut



sRGB gamut in xyY space



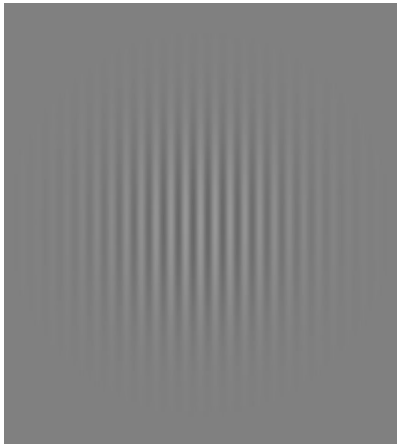
gamut of natural colour in LUV space

Contrast

- The local difference in luminance (or chromaticity) of an object from its surroundings

$$C_{\text{Michelson}} = \frac{Y_{\text{max}} - Y_{\text{min}}}{Y_{\text{max}} + Y_{\text{min}}}$$

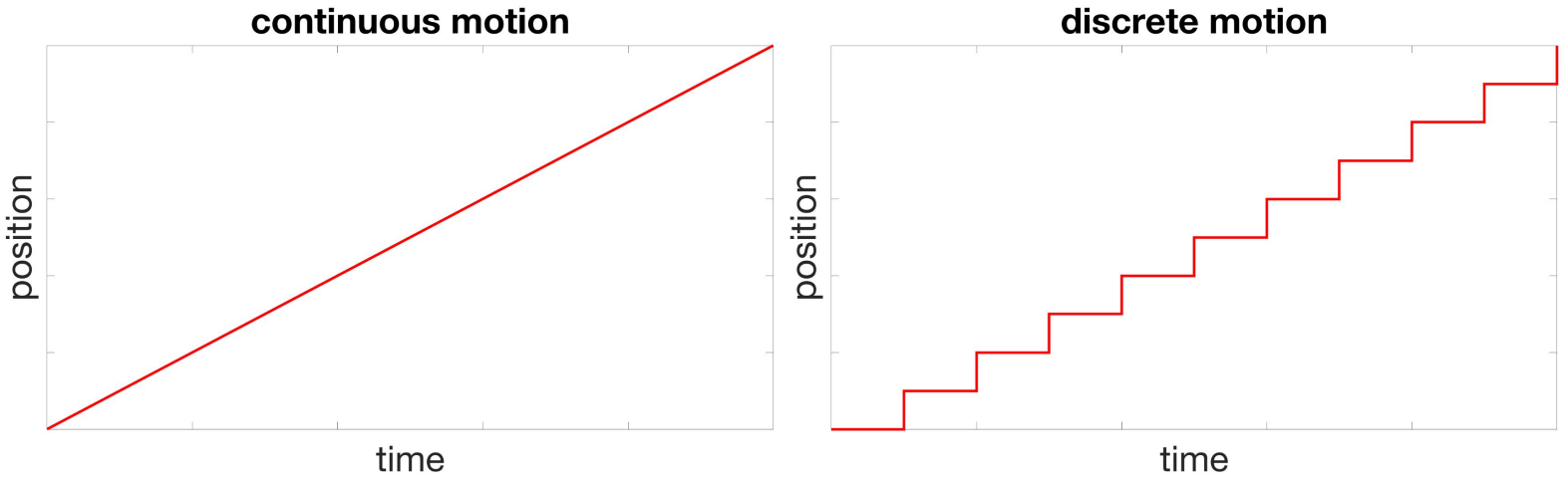
$$C_{\text{Weber}} = \frac{Y_{\text{foreground}} - Y_{\text{background}}}{Y_{\text{background}}}$$



Gabor patch

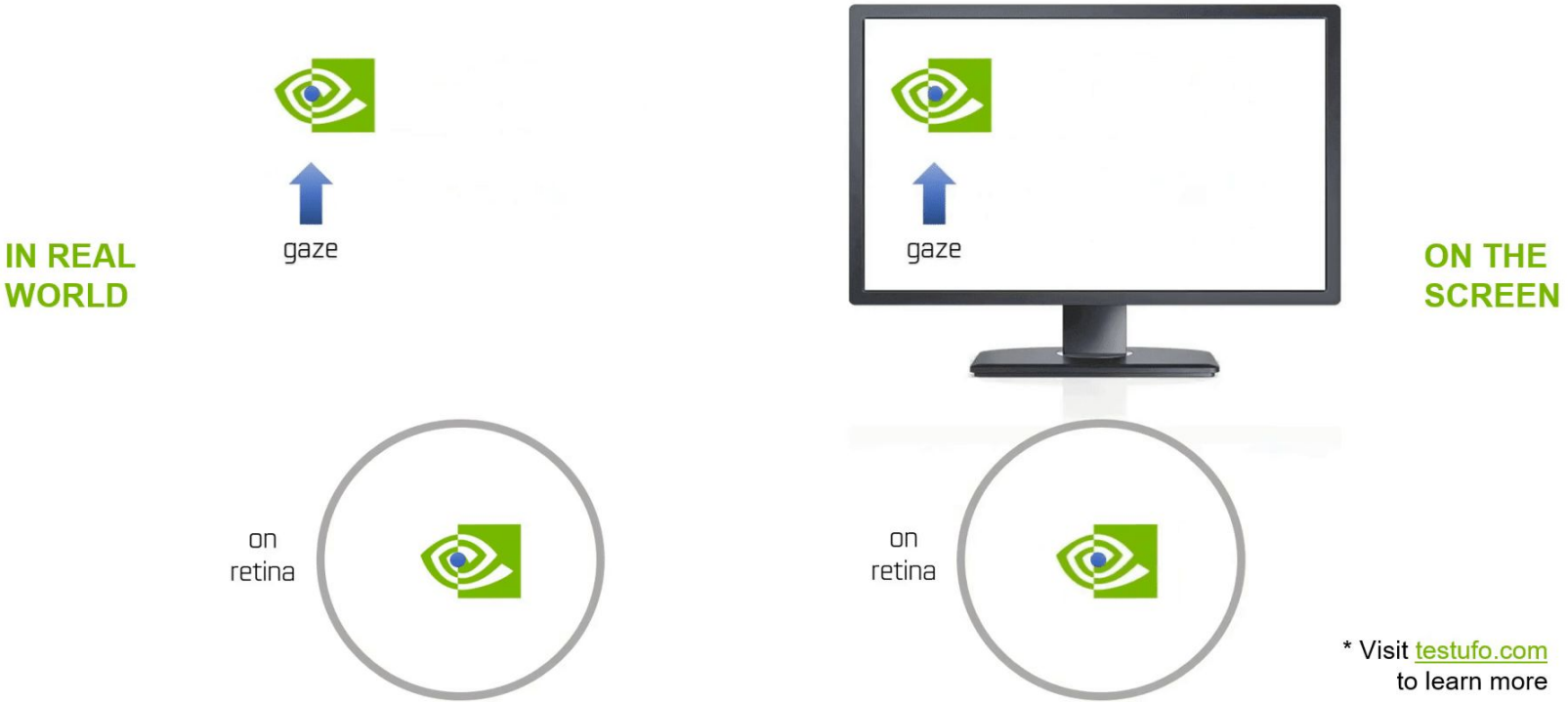
Contrast Sensitivity

Motion Artefacts

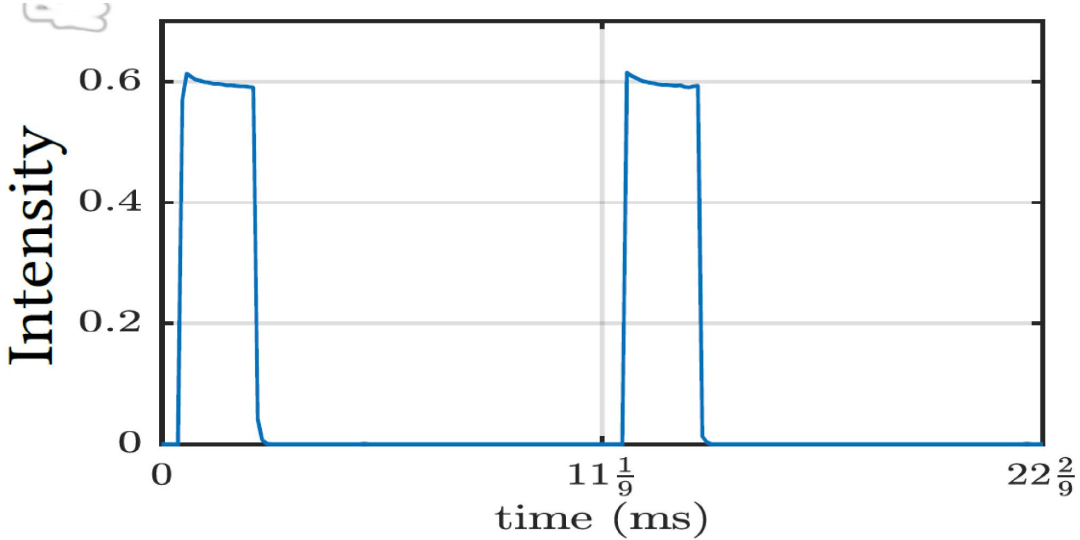


- Juddar
- Hold-type blur
- Flicker
- Stroboscopic effect
- …

Hold-type Blur



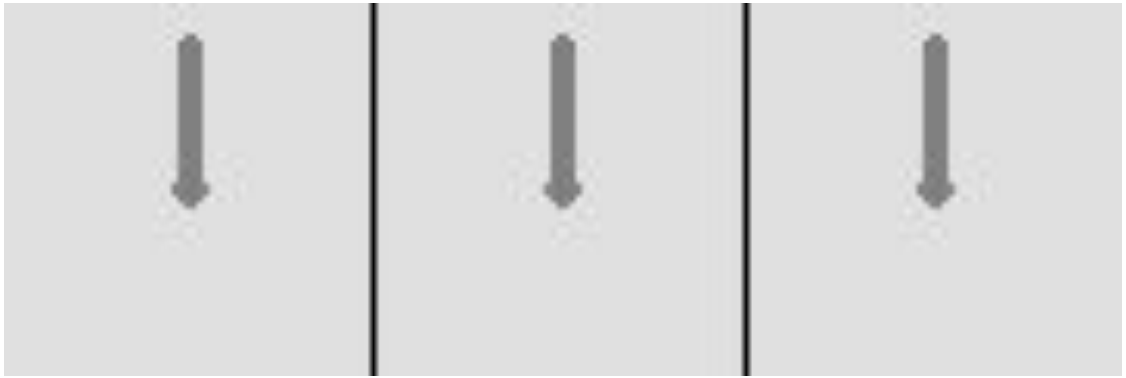
Low Persistence Rendering



- **Critical flicker frequency** (CFF) — the lowest frequency at which flickering stimulus appears as a steady field

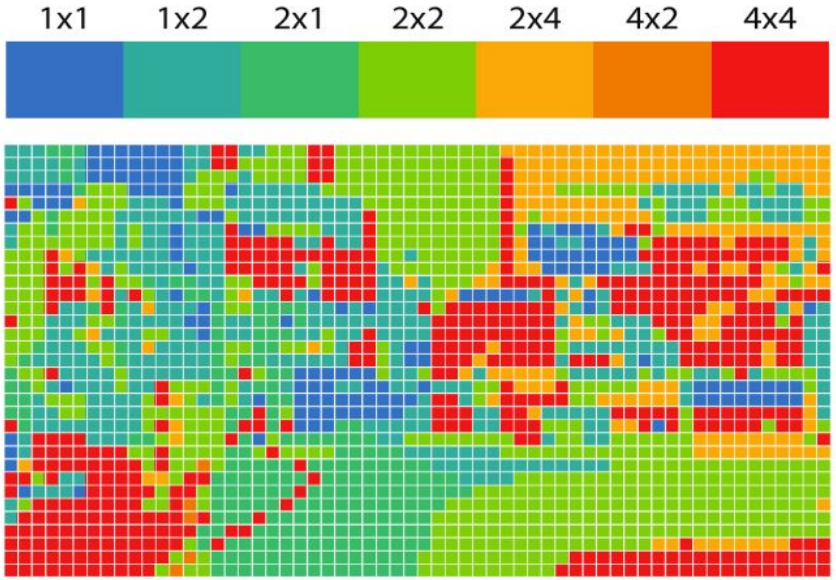
Stroboscopic Effect

- Aliasing that occurs when continuous cyclic motion is represented by a series of short or instantaneous samples at a sampling rate close to the period of the motion



Adaptive Local Shading

Perceptually optimal distribution of shading budget by proposed method



VRS State Map
(Each square represents the shading rate of corresponding 16x16 VRS tile)

Jindal, Akshay, et al. "Perceptual model for adaptive local shading and refresh rate." *ACM Transactions on Graphics (TOG)* 40.6 (2021): 1-18.

Temporal Resolution Multiplexing

- renders every second frame at a lower resolution to save on rendering time and data transmission bandwidth

Denes, Gyorgy, et al. "Temporal Resolution Multiplexing: Exploiting the limitations of spatio-temporal vision for more efficient VR rendering." *IEEE transactions on visualization and computer graphics* 25.5 (2019): 2072-2082.