Perceptual Aspects in Visualization

2018-11-27

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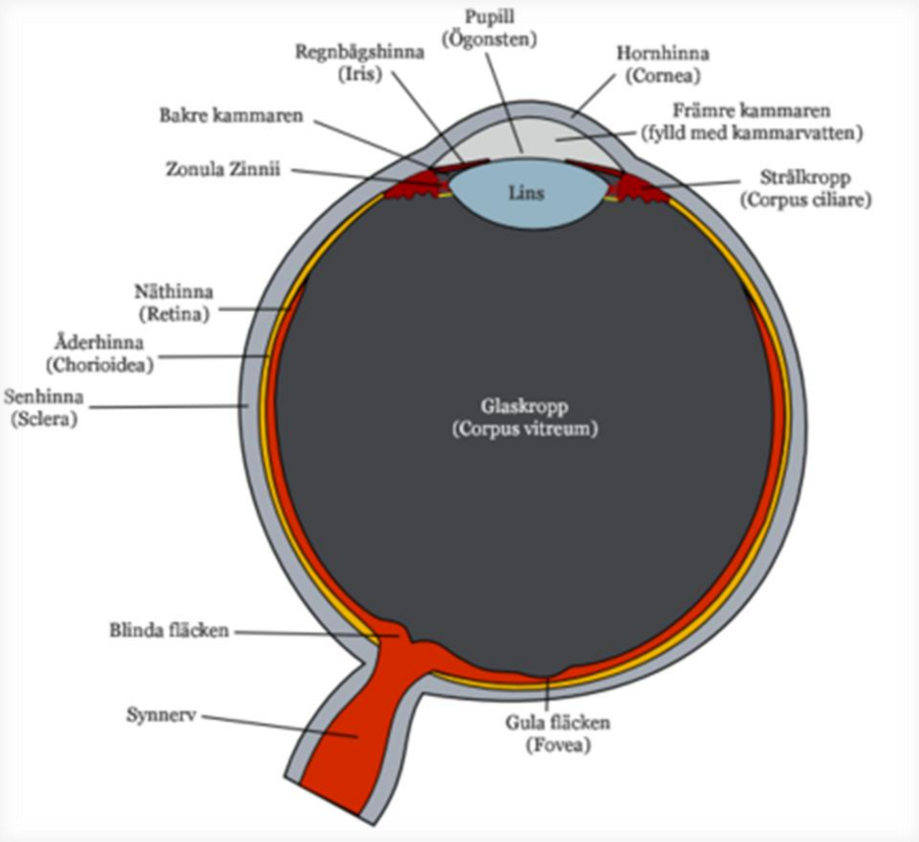
Overview

Quick overview over this lesson

- The Perceptual Foundation
  Physiology & Visual Acuities
- Color, Brightness and Contrast
- Visual Variables
- Use of colors – A Case study
- Pre-Attentive Processing
- Attention & Visual Short Term Memory

Physiology



Pupill
(Ögonsten)
Regnbågshinna
(Iris)
Hornhinna
(Cornea)
Bakre kammaren
Främre kammaren
(fylld med kammarvatten)
Zonula Zinnii
Lins
Strålkropp
(Corpus ciliare)
Näthinna
(Retina)
Åderhinna
(Chorioidea)
Senhinna
(Sclera)
Glaskropp
(Corpus vitreum)
Blinda fläcken
Synnerv
Gula fläcken
(Fovea)

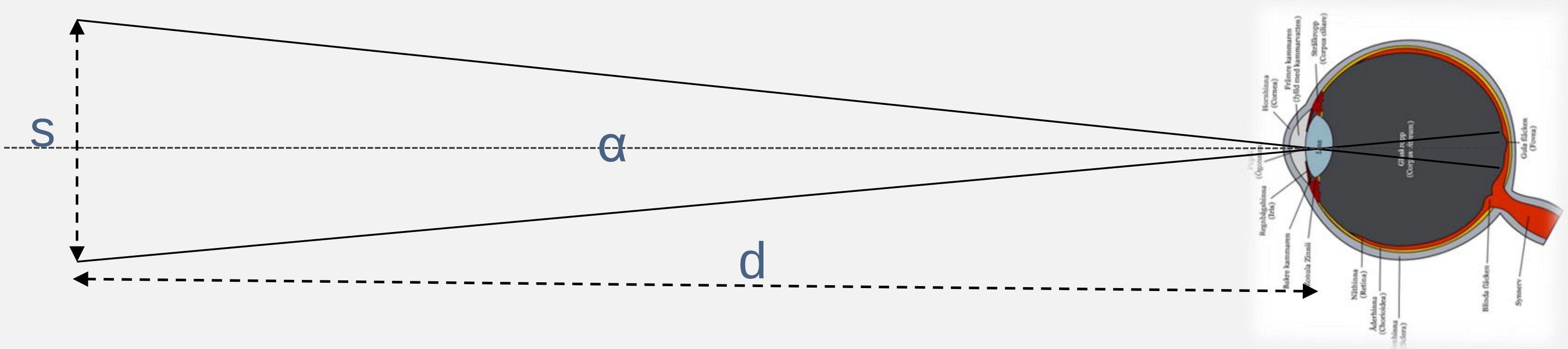
Terminology: Visual Angle

Definition:

Visual angle is the angle α subtended by an object of size *s* at some distance *d* from the observer.

When describing visual acuities and properties, visual angle is used because it specifies sizes of visual stimuli (targets) independent of viewing distances.

$$s = 2 \cdot d \cdot \tan\left(\frac{\alpha}{2}\right); \alpha = 2 \cdot \tan^{-1}\left(\frac{s}{2d}\right)$$



Retina

Rods (sv. stavar):

- Sensitive at low light level
- Approximately 100 million
- Contribute little at daylight (overloaded at daylight levels)
- Are interconnected over larger areas

Cones (sv. tappar):

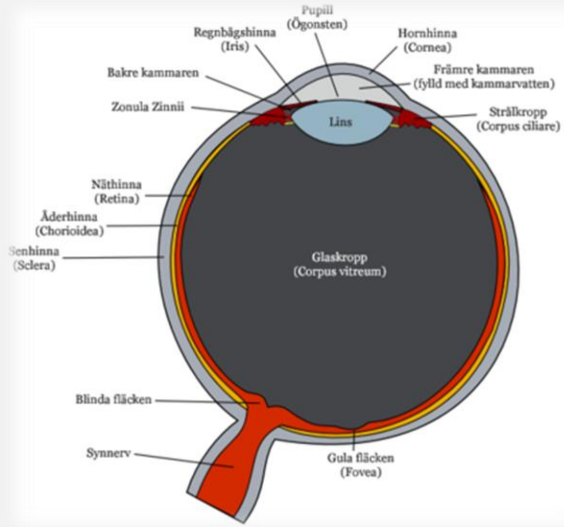
- Effective at daylight levels
- Color sensitive
- Are highly packet at the fovea (**180 per degree visual angle**)
- Approx. 100.000 at the fovea
- Approximately 6 million in total

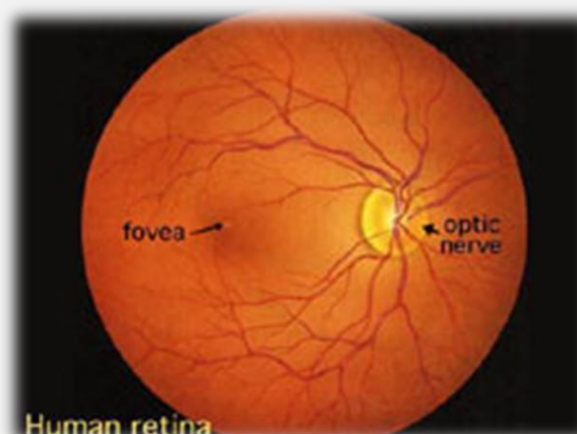
Blind Spot:

- Approx. 15 degrees lateral (→try self test)

Fovea:

- Highest cone density
- Subtends 1,5-2 degree *visual angle*
  (definition of visual angle on next slides)



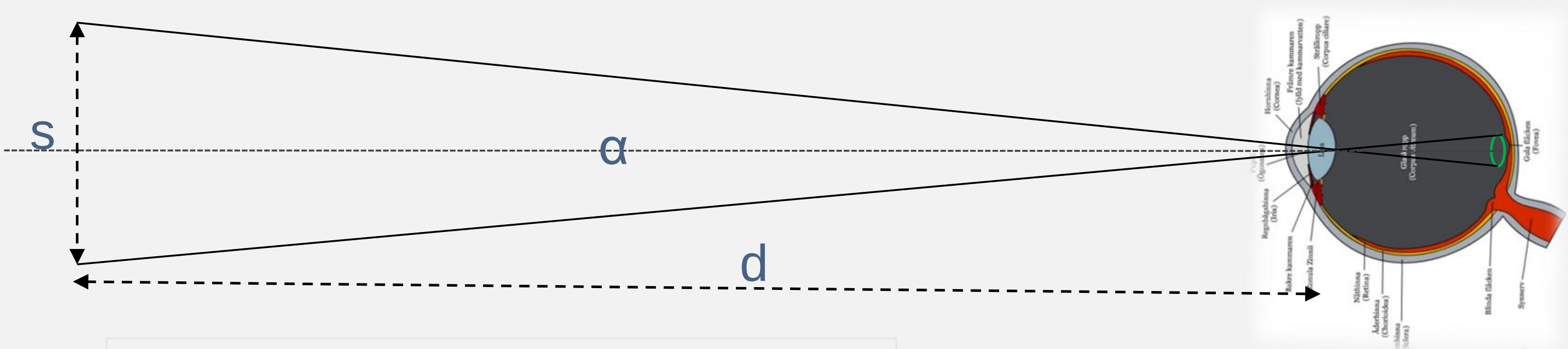


Fovea Visual Angle

Focal field of view defined 1-2 degrees visual angle

Size of a thumbnail at approximately arms length

~2,44 cm at 70 cm viewing distance



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Retinal Receptor Mosaic

- No “regular grid”
- Uneven distribution of S M and L cones
  (less blue sensitive receptors in fovea)
- Sensor “density” is 20 arc sec.
  (180 per degree VA)
- “cone footprint” ~ 0.068 mm
  at 70 cm viewing distance

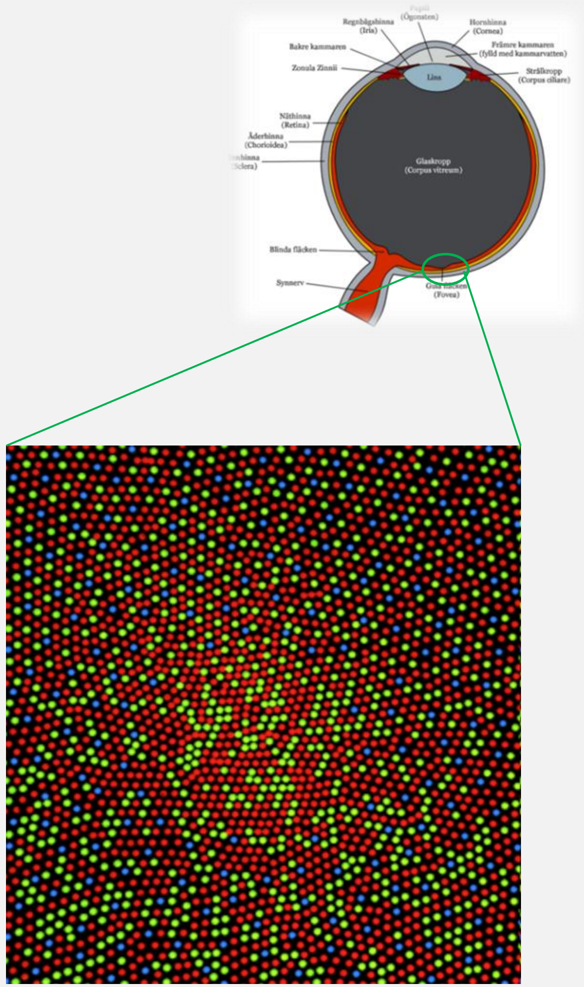


Image adapted from
http://rit-mcsl.org/fairchild/WhyIsColor/
images/ConeMosaics.jpg

Visual Acuities

Point acuity: 1 minute of arc

Grating acuity: 1-2 minutes of arc

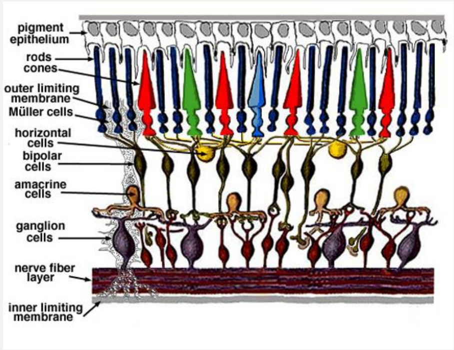
Letter acuity: 5 minutes of arc (5,8 mm at 4 meters distance)

Vernier acuity: 10 seconds of arc

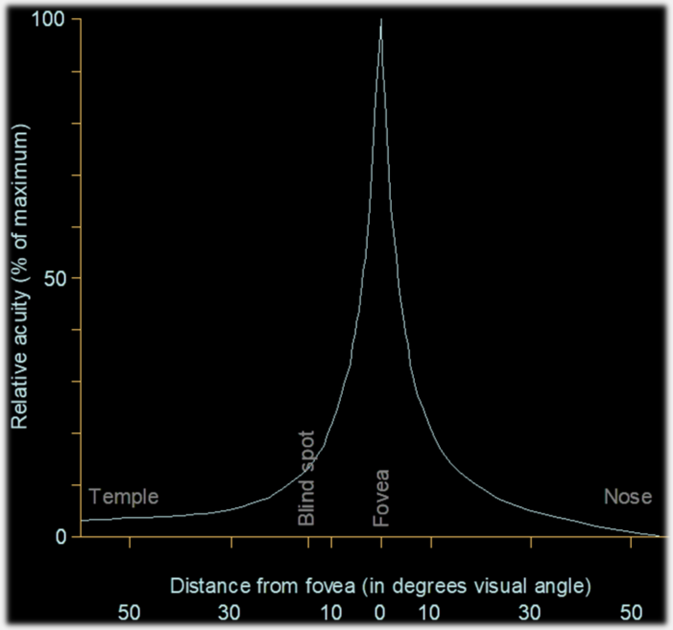
Acuity fall-off across visual field: See figure right

Acuity depends on brightness/contrast

Several receptors interconnected -> **superacuities**

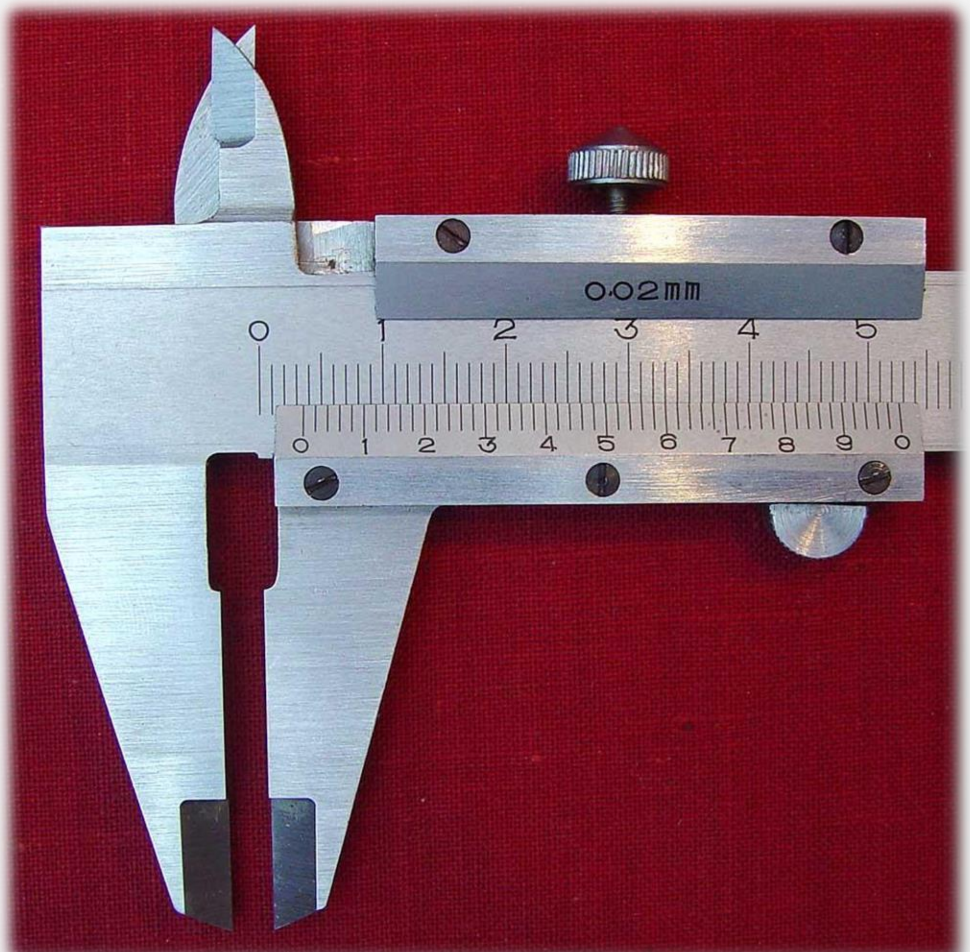


Cones and rods are interconnected in larger regions and respond to visual stimuli



Visual Acuities

Utilization of Vernier acuity: Reading caliper scales



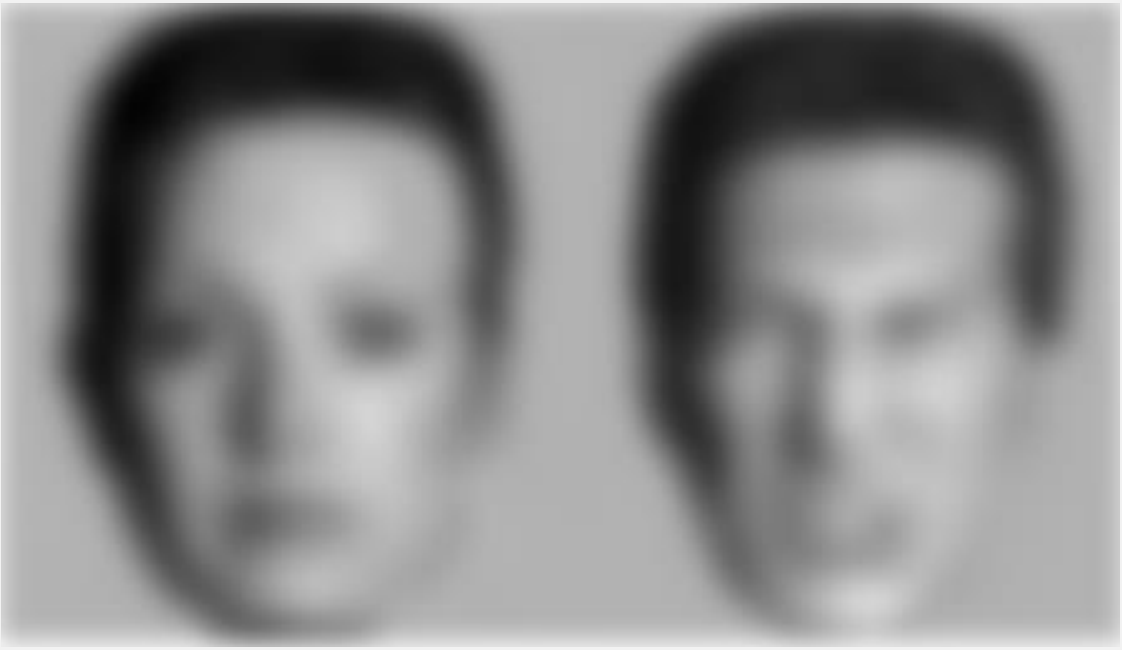
Visual Acuities – Some illusions

Experiment: Visual illusion due to limited retinal resolution

First: Look at this image in full-screen (17” monitor at 70cm viewing distance)
Second: Step back about 4 meters from the screen.

What do you observe? can you explain?

Visual Acuities – Some illusions



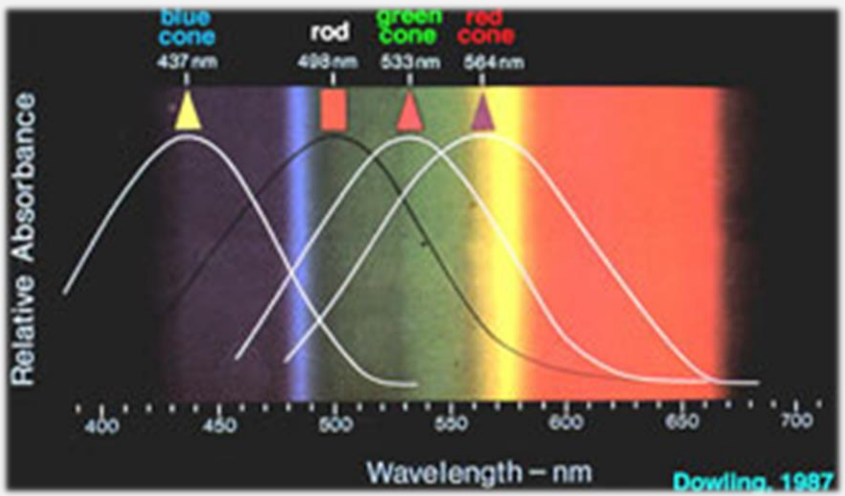
The low-frequency component of the image. At far viewing distances they become prominent because the high frequency spatial components in the image cannot be resolved by the HVS.

Spectral sensitivity of cones

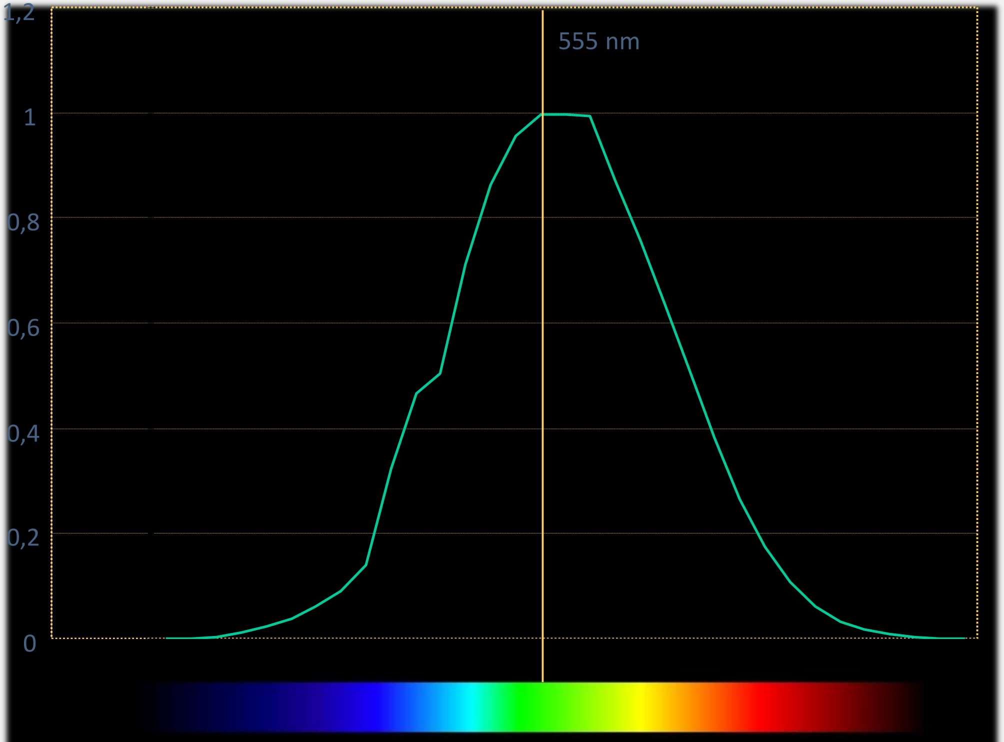
Spectral range of visible light 380nm – 680nm

Spectral sensitivity function

Three peaks: 430 nm, 540nm, 580nm



Relative spectral sensitivity



Relative sensitivity to different wavelength according to CIE (V(l)
(Values from Ware 2005)

Relative sensitivity of the eye

Green 555 nm, peak

Blue 450 nm, 4% of max sensitivity

=> Blue is not a preferred choice in presence of green and/or red

Color discrimination

(SND – smallest noticeable differences)

How many colors should we *represent*?

- Virtually an unlimited number could be used
- In practice we use 24 bit RGB i.e. 16 million different colors

How many colors can the display *reproduce*?

- Not necessarily as many as we *represent*
- Depends on color gamut of the display

How many colors can we distinguish?

- Figures vary from a few up to 10 millions of different colors
- Depends on several factors (stimulus size, environment, …)

Color sensitivity

Assumption: 21 bit RGB representation would yield 2 million different colors.

See the slightly colored text on gray background?

BG = (128,128,128) ; C1 = (128,126,128); C2 = (128,124,128); C3 = (128,122,128)

Can you read this?

Can you read this?

Can you read this?

It depends on field size

BG = (128,128,128) ; C1 = (128,126,128); C2 = (128,124,128); C3 = (128,122,128)

Can you read this?

Can you read this?

Can you read this?

It depends on color

BG = (0,196,0) ; C1 = (0,198,0); C2 = (0,200,0); C3 = (0,202,0)

Can you read this ?

Can you read this?

Can you read this?

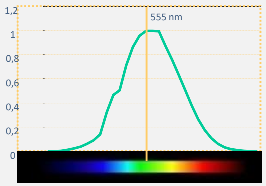
Lens

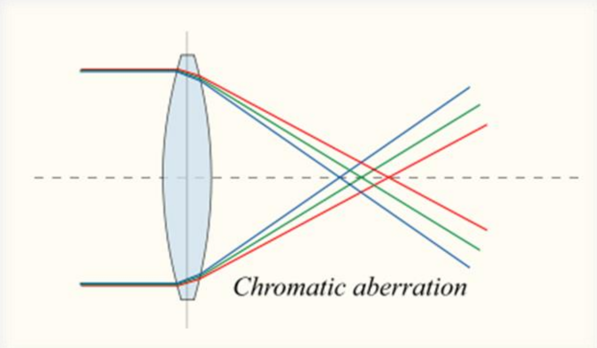
Chromatic aberration

Lens power varies for color

Blue appears "out of focus"

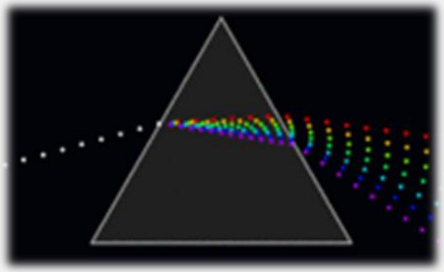
Receptor sensitivity for blue is only 5% of maximum sensitivity for green (recall prev. slide)





Optical power of lens depends on among others

- lens shape
- index of refraction
- wavelength of the light



Dispersion caused by varying refractive index for different wavelengths

Chromatic aberration

and limited spectral sensitivity

impact visual acuities!

The “blurry” blue

Can you read this?

Can you read this?

Can you read this?

Can you read this?

Can you read this?

Can you read this?

Chromostereopsis

Some people see the blue

Closer than the red

But other people see

The opposite effect

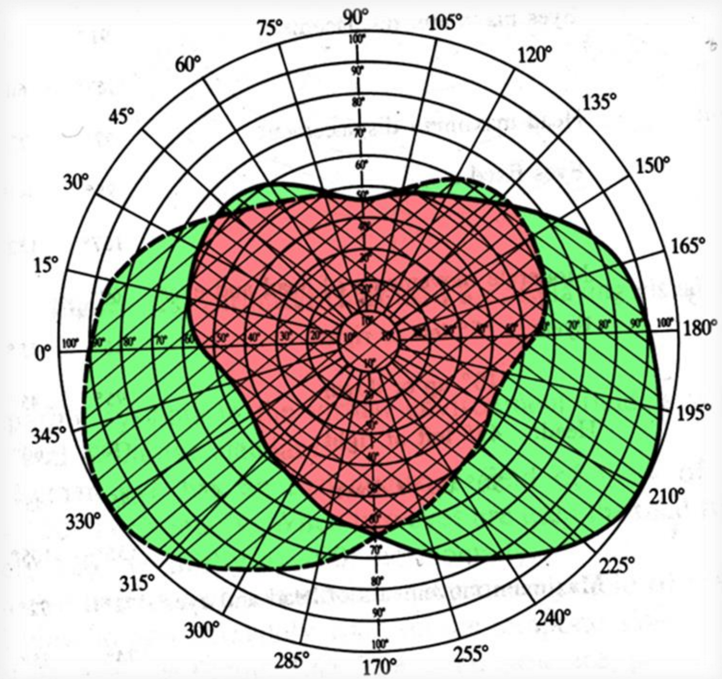
Properties of the visual field of view

Periphery (horizontally up to 200 deg.)

Central FoV (vertically approx. 120 deg.)

Receptor distribution and properties

Stereo-overlap (approx. 120 deg.)



Most prominent figures at 4-5 deg. visual angle

Approximately 6 cm at 70 cm viewing distance

Rapid changes are detected in peripheral field of view

Properties of the visual field of view

Most prominent figures at 4-5 degrees visual angle

Approximately 6 cm at 70 cm viewing distance

Luminance, lightness and brightness

Definitions:

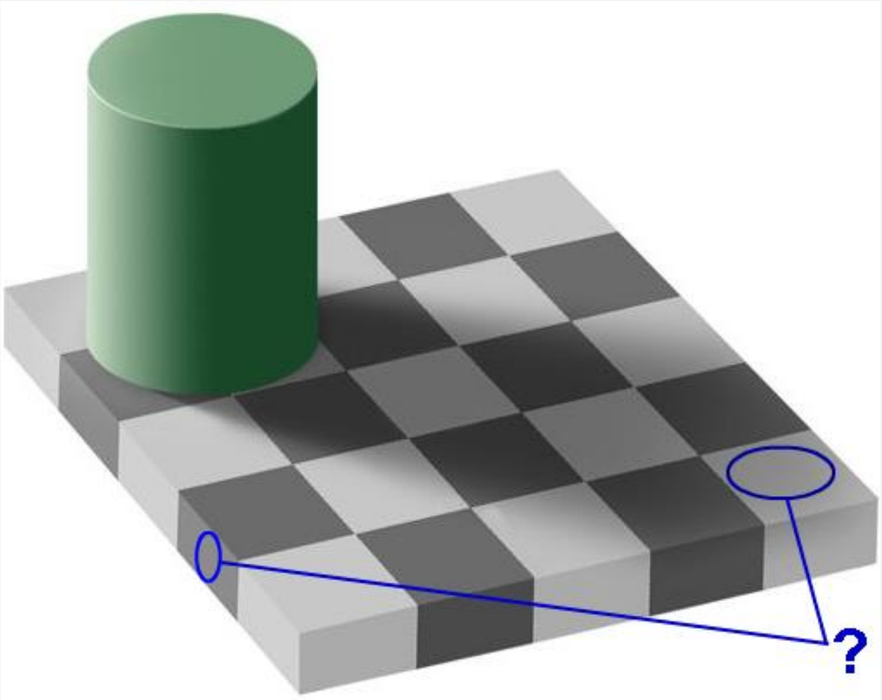
Luminance is the measurable amount of light coming from some region in space . It is a physical property that can be exactly measured (e.g. Candela per square meter).

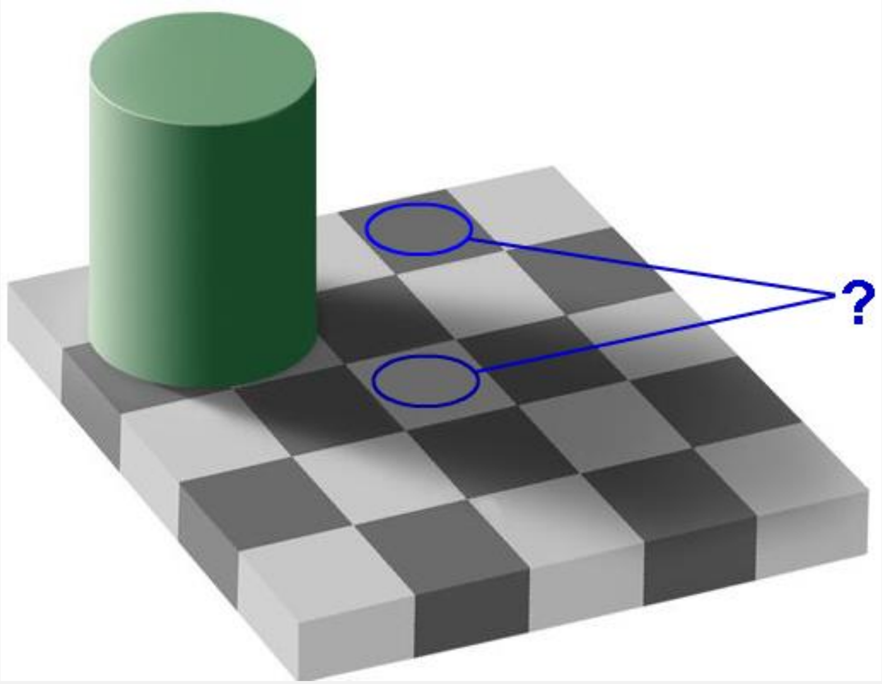
Brightness is the perceived amount of light coming from self-luminous objects.

Lightness refers to the perceived reflectance of a surface. A white surface is light a black one is dark.

Color value assessment

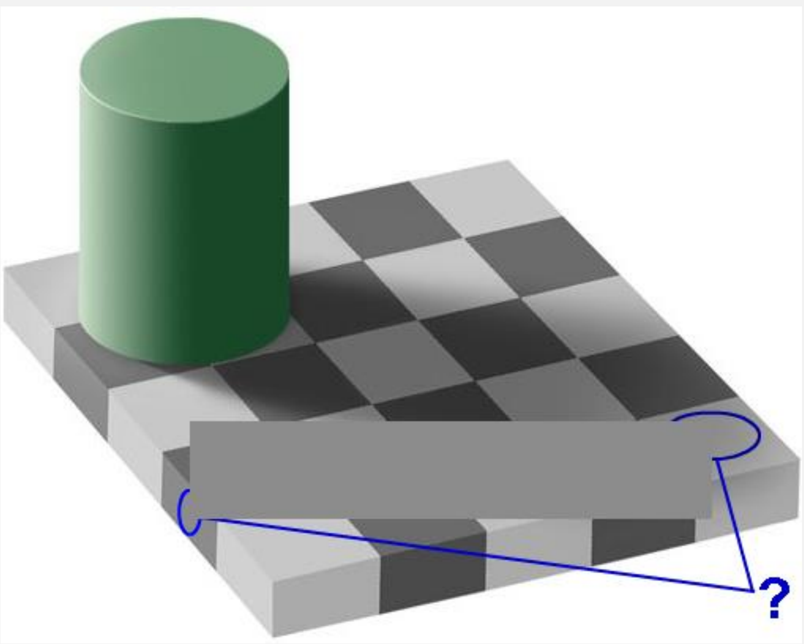
Estimation of the lightness levels of colors depends on surround

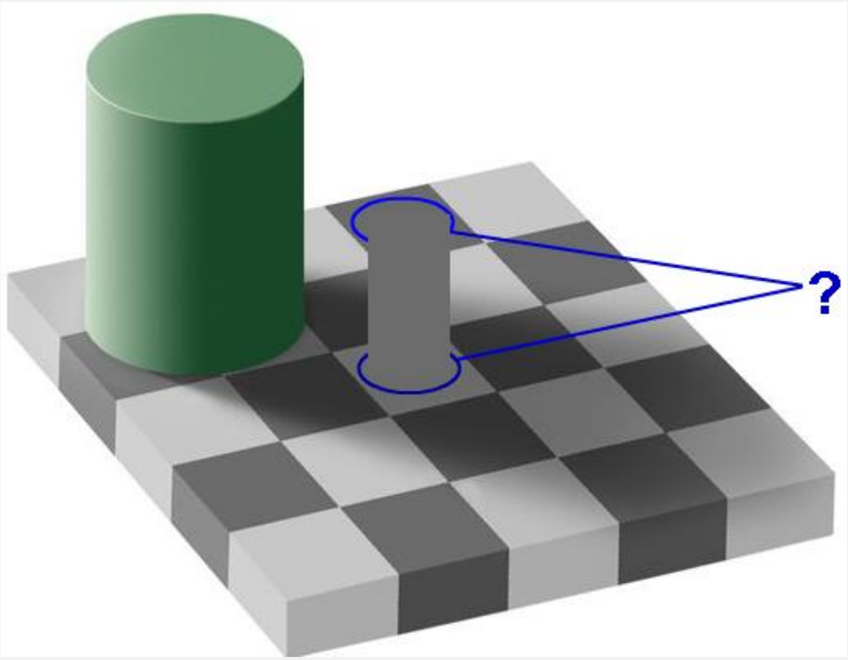


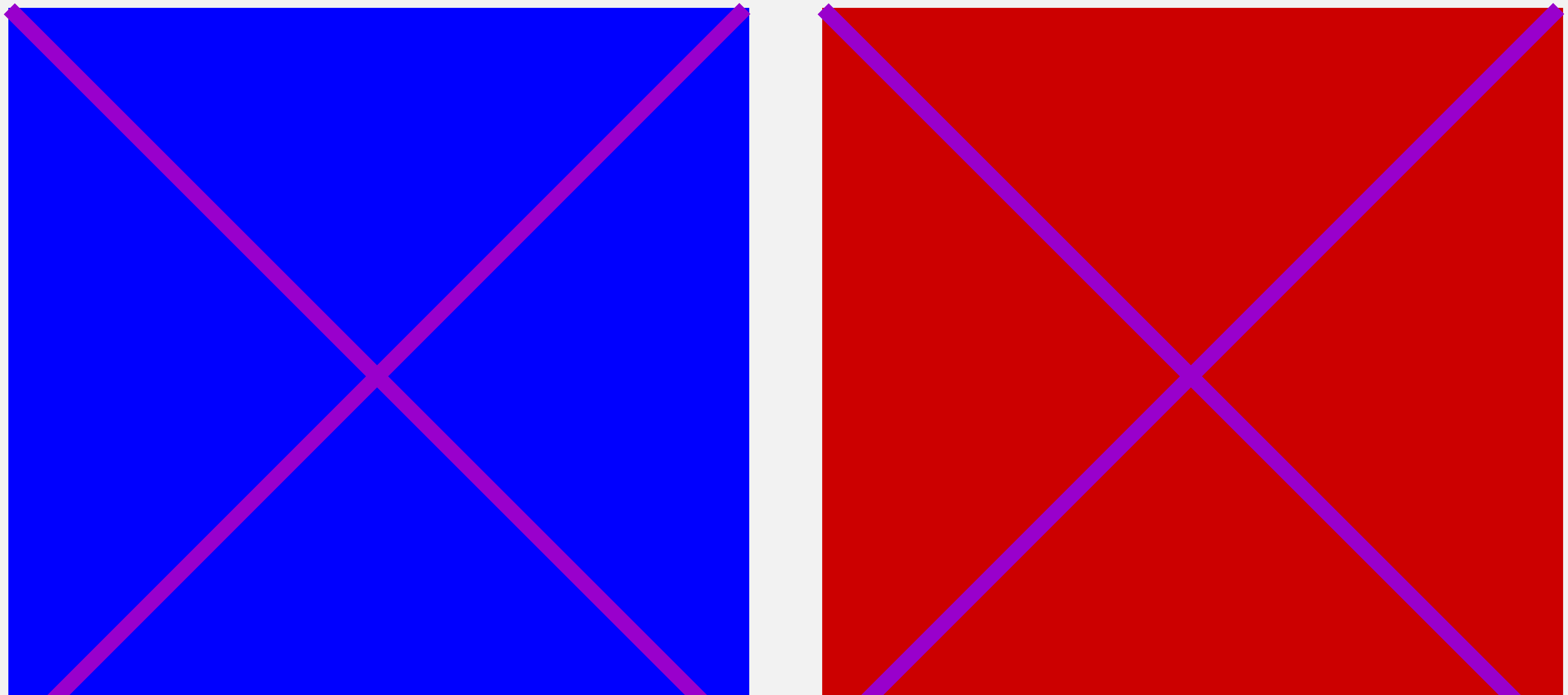


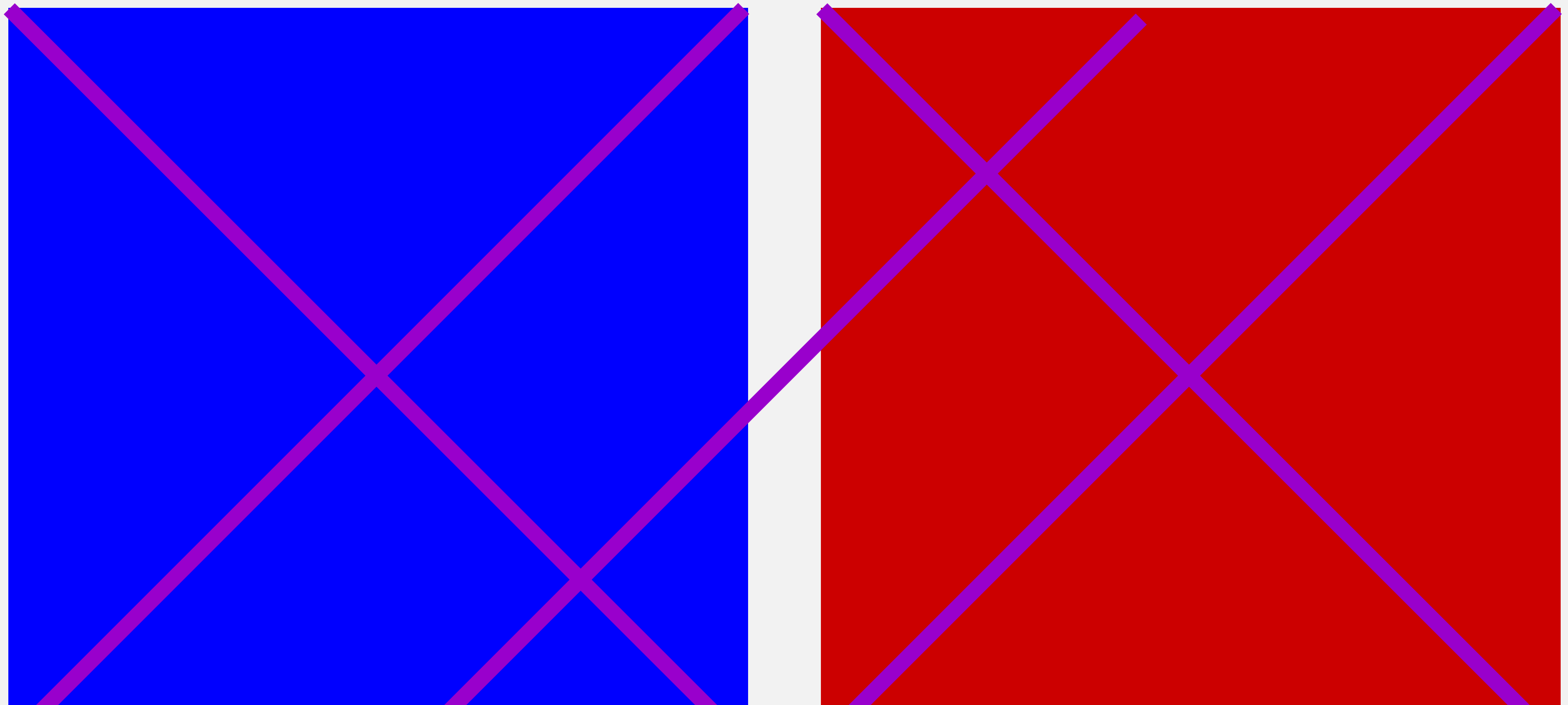
Color value assessment

Color not useful as a means to encode/read absolute value









Interpretation of color

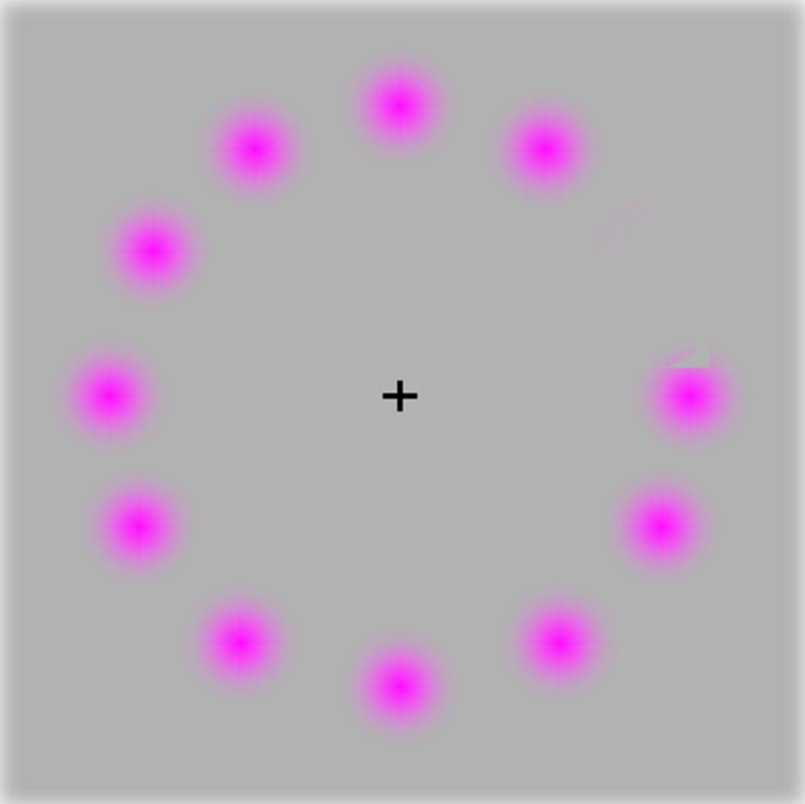
Receptor bleaching (photochemical bleaching)
(-> *visual phototransduction, photopsin, protein-pigment complex*)

Negative afterimages due to photo-pigment depletion

(Helmholtz 1866, Hering 1872)

Example: See next slide

Other explanation in the absence of light: Neurons fire in opposite state after termination of a prolonged stimulus (overshoot).



Color Adaptation

What color is the shirt of the lady not raising her hands?

Color Adaptation

Here is the original image, without filter.

And quite right. The color is yellow!

Color Adaptation

Now lets copy the top from picture 1 into the original picture 2?

Well, the color of the top in picture1 was in fact green!

Color Adaptation

Here is the direct comparison

Contrast

Visual perception is not directly based on the neural signals of the receptors in the retina, instead there is some neural processing in several layers of retinal ganglion cells.

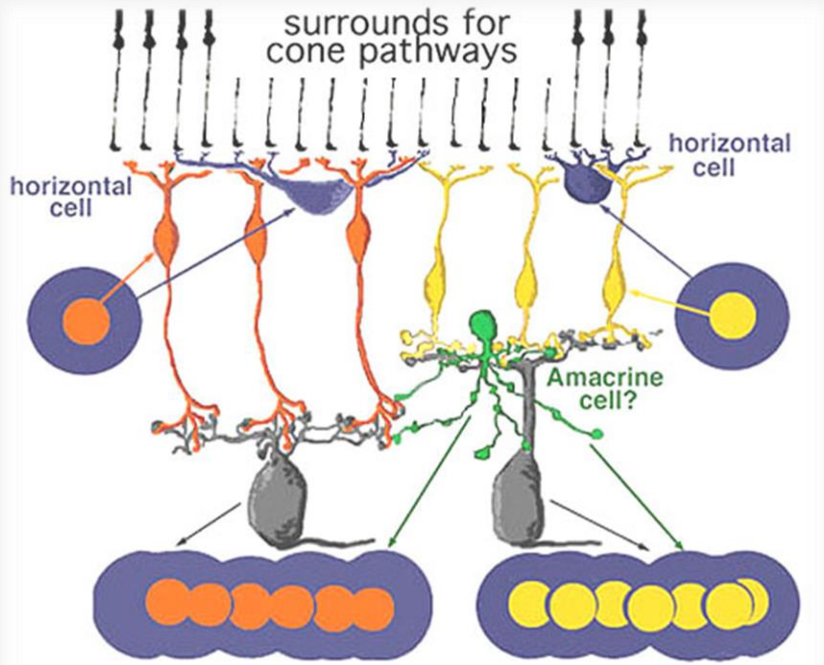
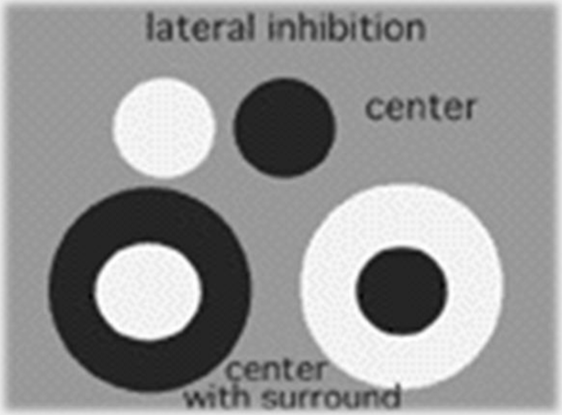


Fig. 15. Diagram of the organization of center-surround circuits using both horizontal cells and amacrine cells.

Contrast

Ganglion cells are organized with circular receptive fields that can have an on-center or off center. Size of receptive fields vary from central field of view to periphery.

Lateral inhibition (Hartline 1940)



Contrast

Difference of Gaussian model (compare figure 3.3)

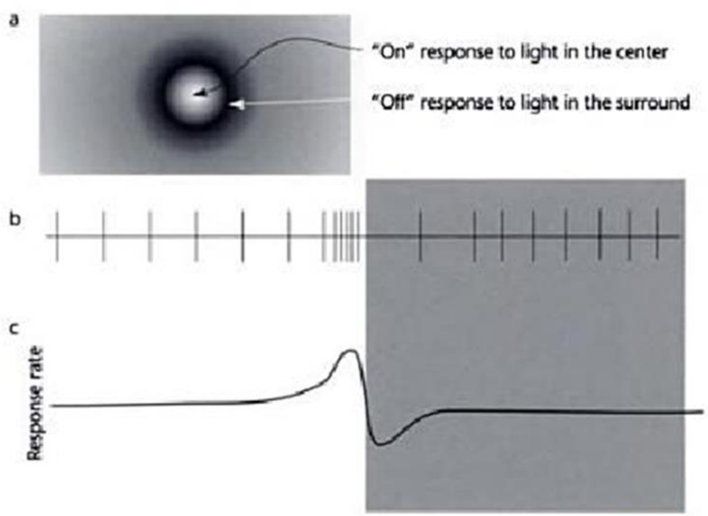


Figure 3.2 (a) The receptive field structure of an on-center simple lateral geniculate cell. (b) As the cell passes over from a light region to a dark region, the rate of neural firing increases just to the bright side of the edge and decreases on the dark side. (c) A smoothed plot of the cell activity level.

Figure 3.3 Difference of Gaussians (DOG) model of a receptive field.

Simultaneous contrast

The DOG processing model facilitates enhanced perception of contrast -> *simultaneous contrast*

Color Ramp example

See more examples on next slides

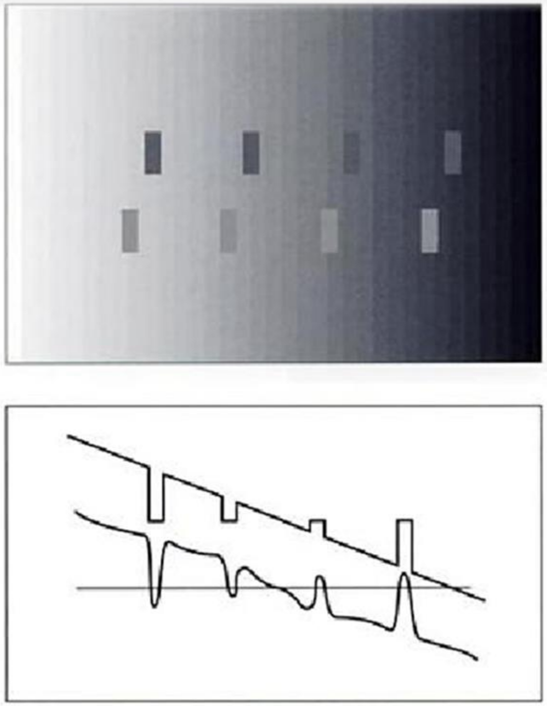


Figure 3.5 Illustration of simultaneous brightness contrast. The upper row contains rectangles of an identical gray. The lower rectangles are a lighter gray, but are also all identical. The graph below illustrates the effect of a DOG filter applied to this pattern.

Visual Assessment of Color

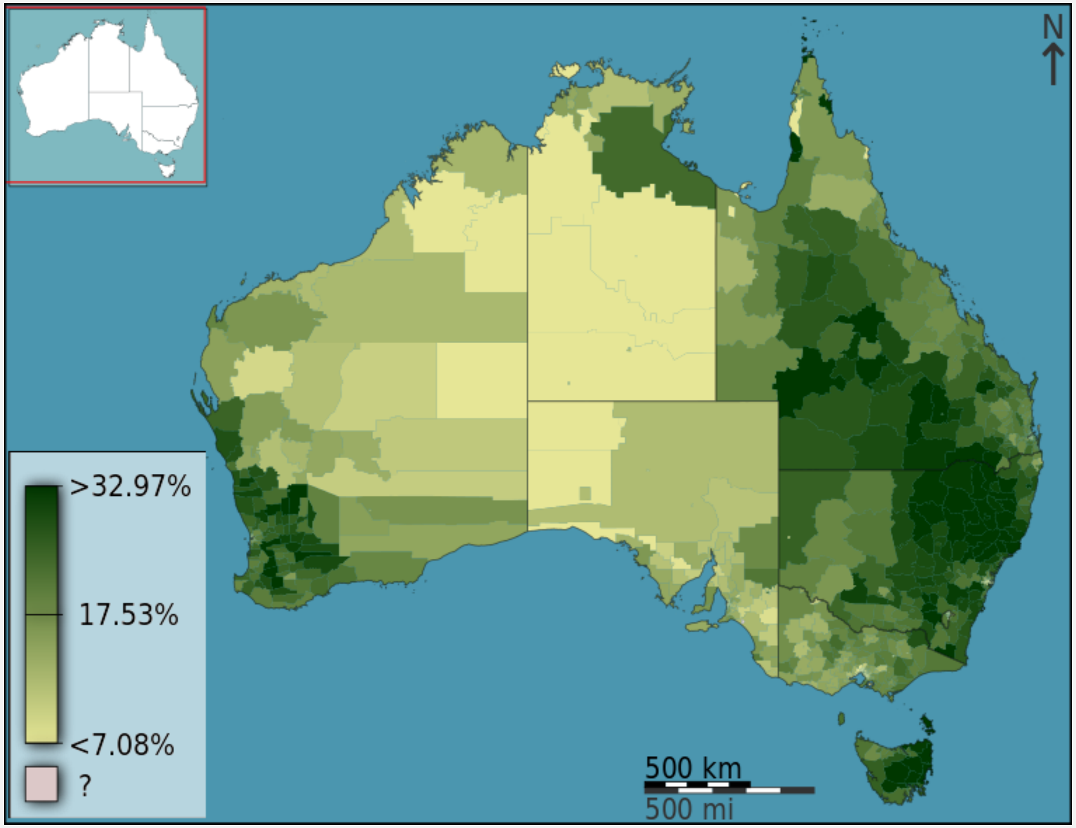
In summary: The human visual system is not an absolute measuring device.

Perception of color and value depends on a number of factors:

- Overall ambient light adaptation level
- Photo pigment depletion (causing “negative” after images)
- Local contrast effects
- Colors in the surround of an object (see illusion picture)
- The illuminant and spatial illumination conditions (see illusion next slide)

Why this is important to stress…

Example: Choropleth maps



What can you tell from this visualization and what should you better not?

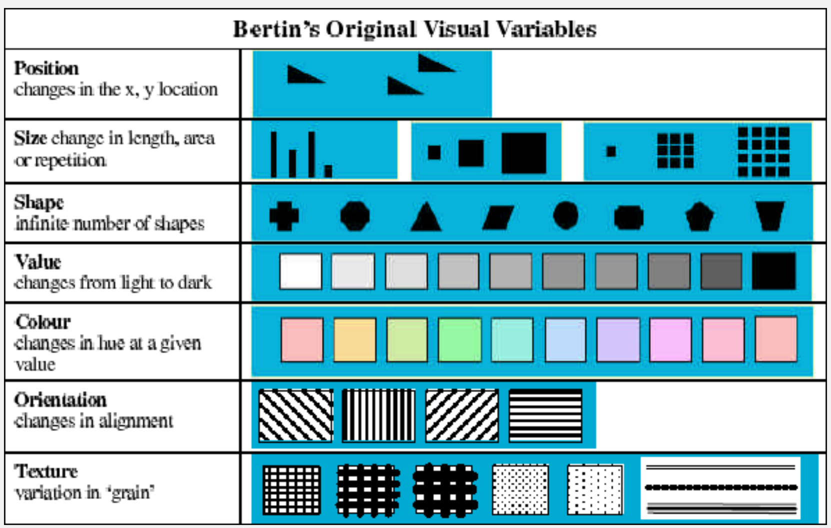
Visual Variables

Visual variables

Moving from low-level visual perception to higher level concepts of visual perception

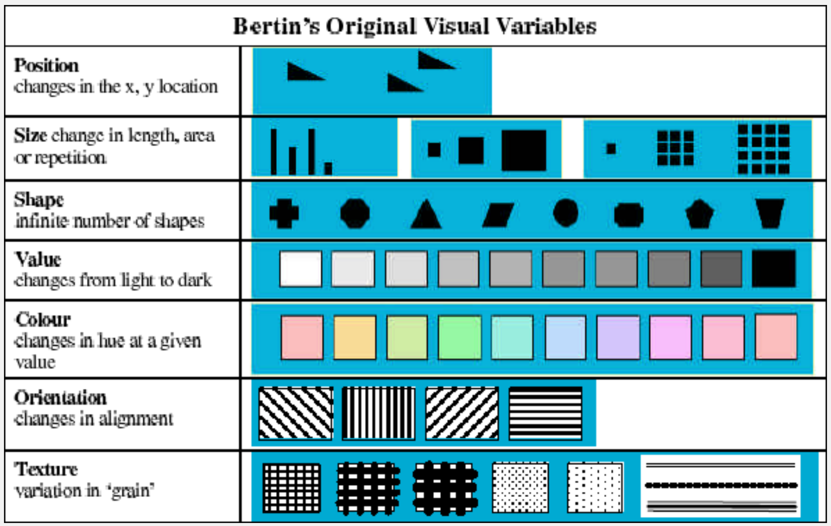
Visual variables or *graphical variables* are fundamental attributes/properties that characterize the appearance of a visual representation.

Defined in similar ways in cartography (Bertin, Mac Eachren e.g.) and information visualization (Mackinlay, Munzner, e.g.)



Jacques Bertin, Semiology of Graphics: Diagrams, Networks, Maps. Translated by W. J. Berg. University of Wisconsin Press 1983 (in french 1967)

Visual variables



Bertin's (French cartographer) assumptions:

- printable on paper
- visible at a glance
- book reading conditions (illumination&distance)

For computer based visualization also

- z-position (stereo or monoscopic cues)
- Opacity (e.g. alpha-compositing)
- Motion (directional/rotational)
- Dynamic deformation (rigid, non-rigid)
- Blink
- Illumination/shading

  (dull, shiny, etc…)

Visual Variables
Task-relevant characteristics

Selective: If a change in this variable allows us to selected an item from other items in a group.

Associative: Change in this variable is enough to perceive as group while changes in other visual variables are present.

Quantitative: If a change in this variable can be interpreted numerically (absolute judgement).

Order: If the variable supports ordered reading. This means that a change could be read as e.g. “more” or “less” (relative judgement).

Length: How many different levels in this variable can be distinguished perceptually)

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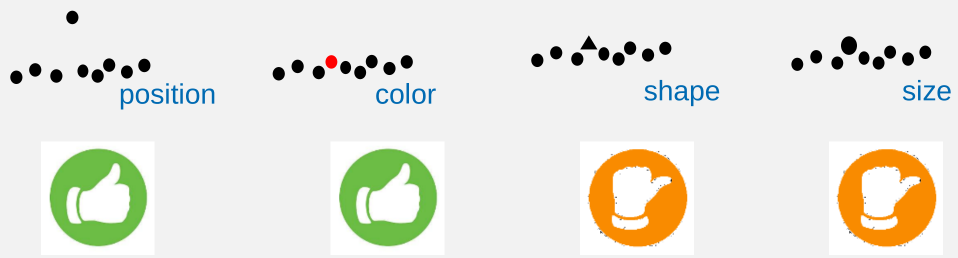

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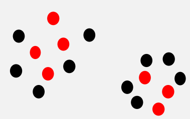
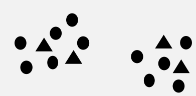
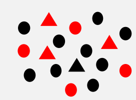


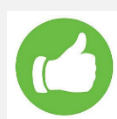
color and position

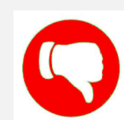


shape and position



shape and color





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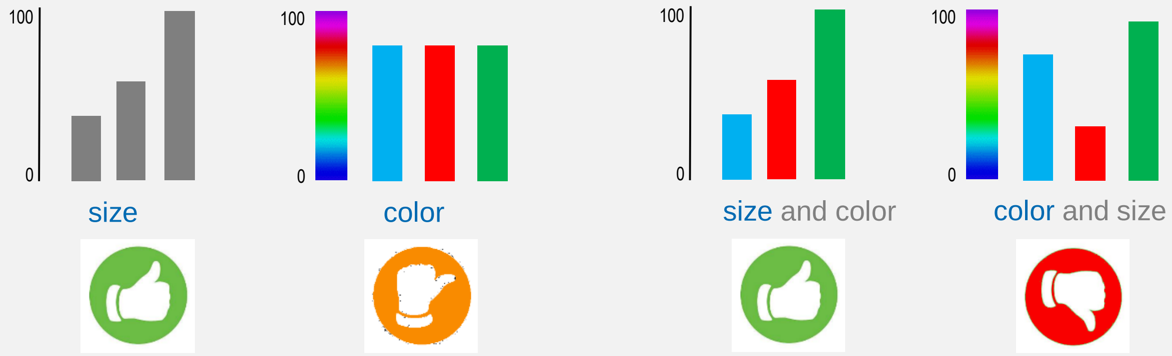

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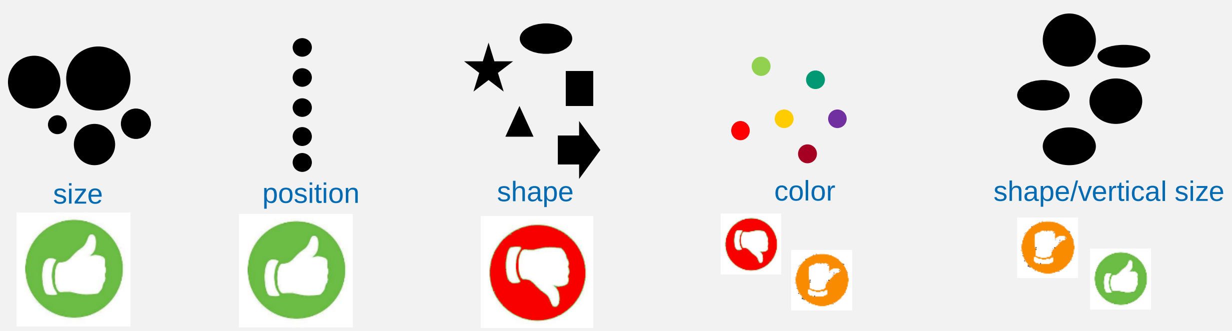

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Length: How many different levels in this variable can be distinguished (perceptually)

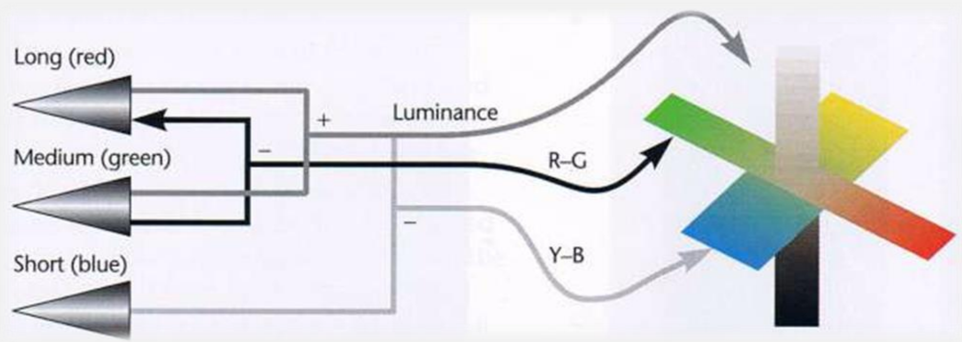
Example size: How small a difference in size of a visual item on screen can be recognized and how large can an item be in practice?
Example color: How small a difference in color of a visual item on screen can be recognized e.g. in visual search, identifying items or reading ?

“My list” of visual variables & intrinsic connotations

	Example	Quantify	Order	Select
Position		Top ⟶ much ; Bottom ⟶ little Left ⟶ little ; Right ⟶much	Left ⟶ first ; Right ⟶ last Top ⟶ best ; Bottom ⟶ worst	Based on gestalt ⟶ outliers
Tilt/angle		Vert. ⟶ much ;Horiz, ⟶ little	Vert. ⟶ strong;Horiz, ⟶ weak Vert. ⟶ good;Horiz, ⟶ bad	Based on gestalt ⟶ outliers
Size 1D – Length		Short ⟶ little ; Long ⟶ much	Long ⟶ first ; Short ⟶ last	Longest ⟶ stands out
2D – Area		Small ⟶ little ; Large ⟶ much	Context dependent	Largest ⟶ stands out
3D – Volume		Small ⟶ little ; Large ⟶ much	Context dependent	Largest ⟶ stands out
Depth (3D)		Not clear	Near ⟶ first; Far ⟶ last	Near ⟶ important
Color Luminance		Dark ⟶ much ; Light ⟶ little But can be reverse! (Radiology)	Dark ⟶ certain Light ⟶ uncertain	Saturated ⟶ certain Desaturated ⟶ uncertain
Saturation		Sat. ⟶ much ; Desat.⟶ little But can be reverse!	Saturated ⟶ certain Desaturated ⟶ uncertain	Saturated ⟶ pops out
Hue		Difficult to be used ⟶ Keys are needed	Few intuitive orders ⟶ Rainbow, Hot/Cold, Heated Iron	Any hue ⟶ pops out (if surround is desaturated)
Curvature		?	Depends on convention	Based on gestalt ⟶ outliers
Shape		?	Depends on convention	Depends on convention
Motion		?	?	Moving item ⟶ pops out

Speaking of color…..

Opponent Process Theory



Cone signals are hierarchically combined and processed in three channels:

Yellow-Blue (R+G-B)

Red-Green (R-G)

Black-White (R+G+B)

Ewald Hering (1920)

- Six base colors (unlike trichromacy theory)
- Differential and additive processing of receptors signals
- Naming-, cultural and neurophysiological support for this theory

Color as label

Ethnographic studies

Most frequent colors

Number of colors we can distinguish
vs. number of different colors we can tell?

Colors that are not basic are difficult to remember
(orange, lime green …)

Criteria for use of color as label
Distinctness, uniqueness, contrast with background,
color blindness, number, field size,
conventions

Brown
Pink
Purple
Orange
Gray

Color as label
Conventions and learned knowledge

Name the colors of the words!

Yellow

Green

Blue

Orange

Gray

Red

Green

Color as label
Conventions and learned knowledge

Name the colors of the words!

Yellow

Green

Blue

Orange

Gray

Red

Green

Colors can show detail

Example: Reading complex documents on a handheld mobile device
(-> see letter acuity)

Remember: Visual acuities depend on lightness contrast
-> most important for readability of text and fine structural detail

Therefore: Visual acuity depends on large ΔL of (color) stimuli

Perceptual dimensions of color:

Hue (chromaticity, spectral wavelength)
Saturation (purity, degree of white)
Lightness (value, level)

Colors can show detail

Colors differ in hue

Text_{HSL}=(200,128,128)

Background_{HSL}=(72,128,128)

Can you read this?

Colors differ in saturation

Text_{HSL}=(200,128,128)

Background_{HSL}=(200,0,128)

Can you read this?

Colors differ in luminance

Text_{HSL}=(200,128,128)

Background_{HSL}=(200,0,128)

Can you read this?

Colors can show detail

Take-away-message: Appropriate choice of colors is important depending on the intended use/effects.

If contrast is the objective, use color pairs with large ΔL

Examples:

- Spatial details (e.g. text)
- Contours and shape in color maps

Minimize ΔL for color pairs if lo-contrast is the objective

Example:

- Reduce risk for visual stress
- Avoid undesired artifacts (mach-banding)
- De-emphasize regions with less relevance (lower attention)

Pre-attentive visual processing

Preattentive processing of visual information is performed automatically on the entire visual field detecting basic features of objects in the display. Such basic features include colors, closure, line ends, contrast, tilt, curvature and size. These simple features are extracted from the visual display in the preattentive system and later joined in the focused attention system into coherent objects. Preattentive processing is done quickly, effortlessly and in parallel without any attention being focused on the display. [Treisman, 1985, Treisman, 1986]

Typically, tasks that can be performed on large multi-element displays in less than 200 to 250 milliseconds (msec) are considered preattentive. [Healey, 2005]

- Saturated colors on an achromatic (desaturated) background/context are processed **preattentively**.
- Identification of colored features in this context requires no focused attention / cognitive processing.
- Pre-attentively processed features are useful for rapid search tasks!

Visual Pop-out

Definition of visual pop-out

Visual pop-out occurs when visual features are processed pre-attentively.
I.e. in a visual task involving identification of visual targets, the time needed for identification is not depending on the number of the non-target elements (distractors).

Chroma differences are useful for visual pop-out.

Ready for a test?

A set of characters (letters and numbers). Exactly how many numbers do you count!

Visual Pop-out

Example 23+?

Visual Pop-out

Example 45+?

Visual Pop-out

Example 23+4

Visual Pop-out

Example 45+4

Colors represent quantities

Color maps -> representation of relatively ordered data/values

Perceptual linearity

Constant lightness contrast

Color maps for deviation detection

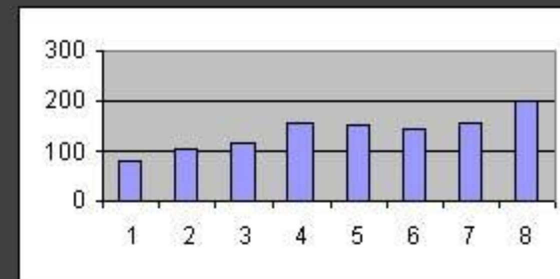
Not suited for absolute quantitative assessment!

Experiment: Sorting color-sequences

Use of color – Color sequences

Correct solution 1 : Heated Iron

Experiment



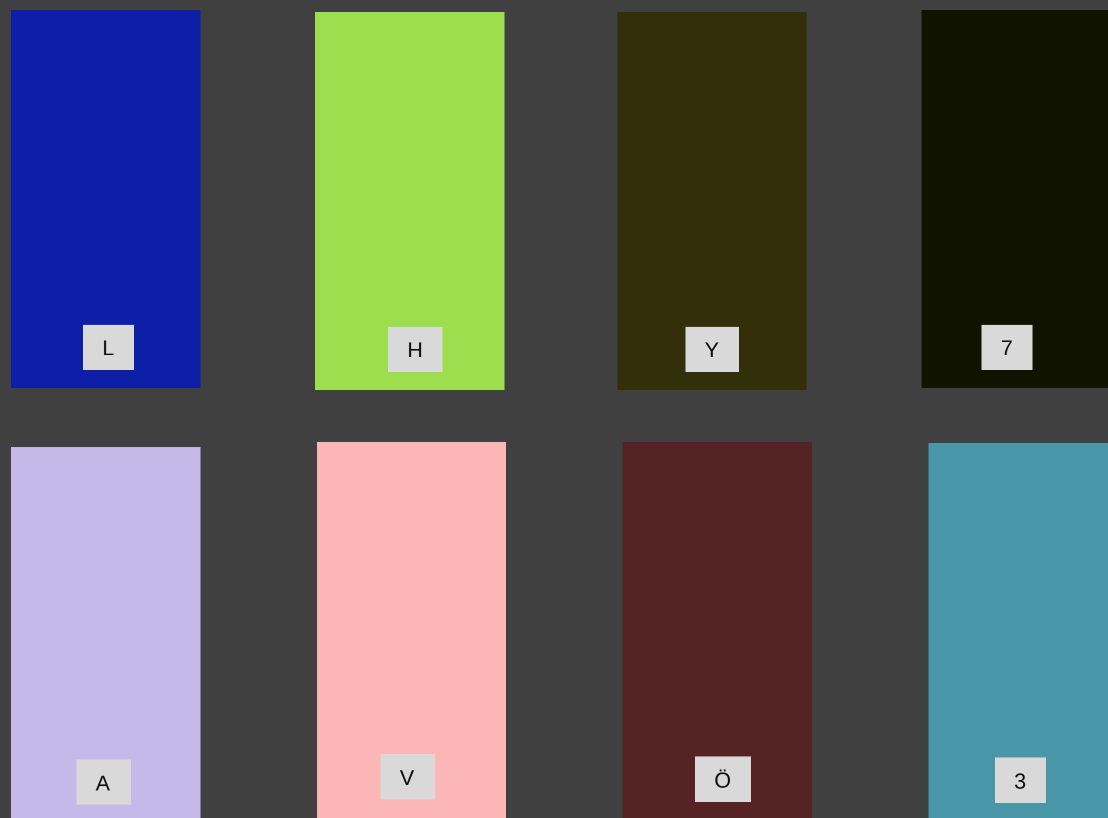
L	81	102	117	156	153	143	155	203

Use of color – Color sequences

Correct solution 2: Gray scale

Experiment

Color sequences (maps) : Experiment

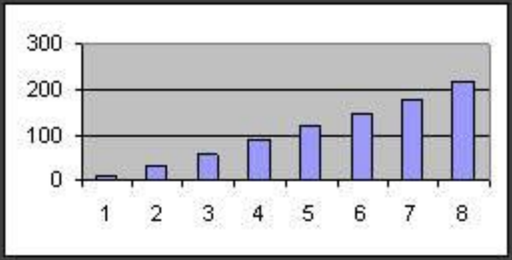


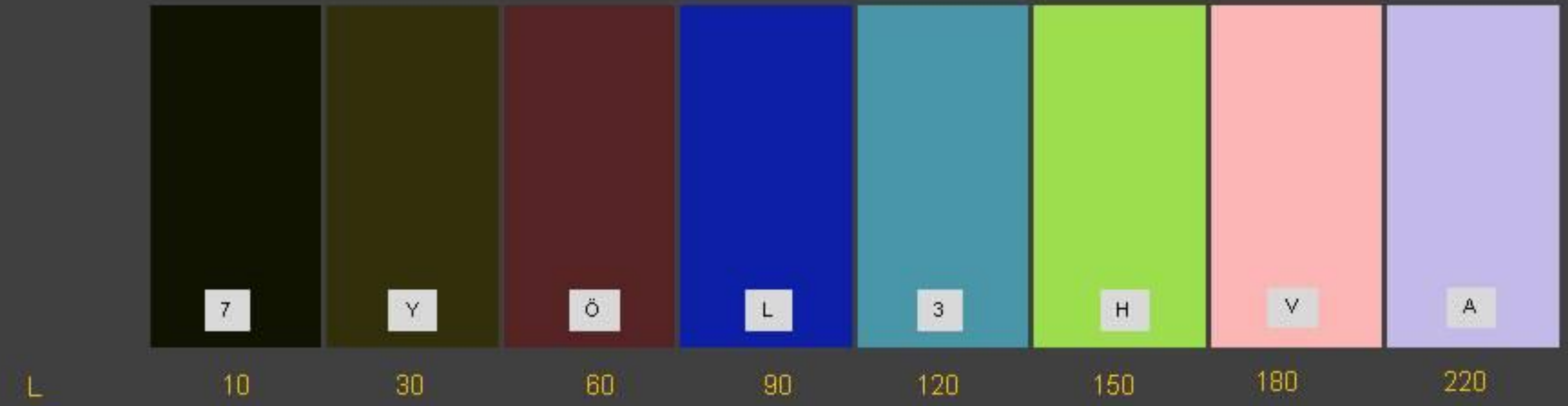
Sort the colors by whatever order you imagine meaningful!

Use of color – Color sequences

Correct solution 3: Random H, >L

Experiment





Use of color – Color sequences

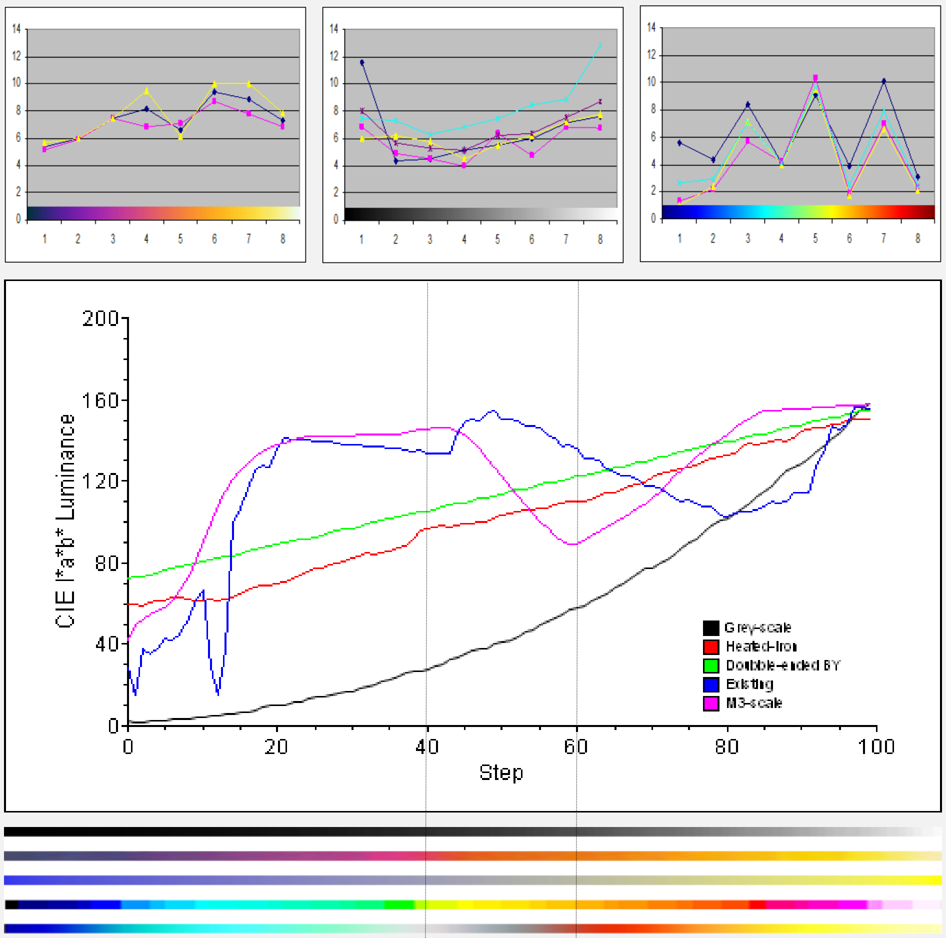
Correct solution 4: Spectral, constant S+L Experiment

Example from a real case in the process industry

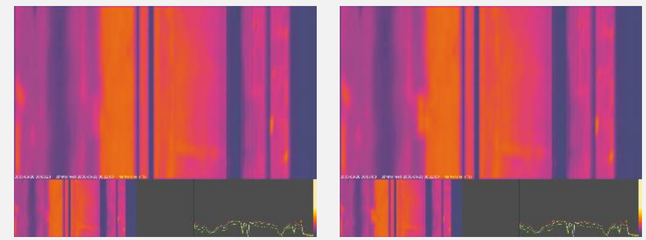
Efficient use of color

Pre-studies

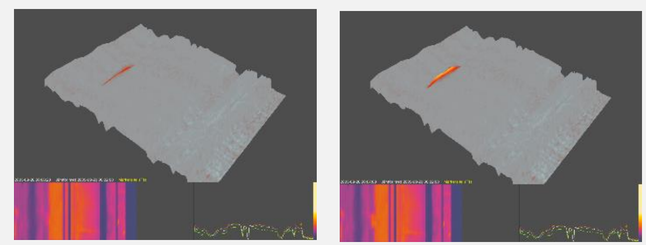
Color mapping designs for JND tasks



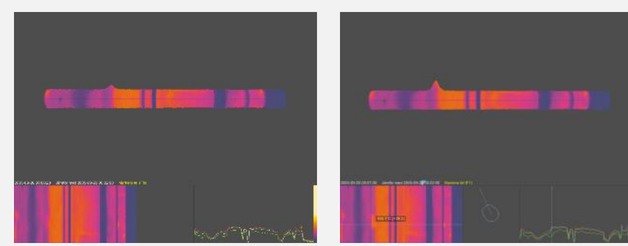
Graphical mappings



2D map

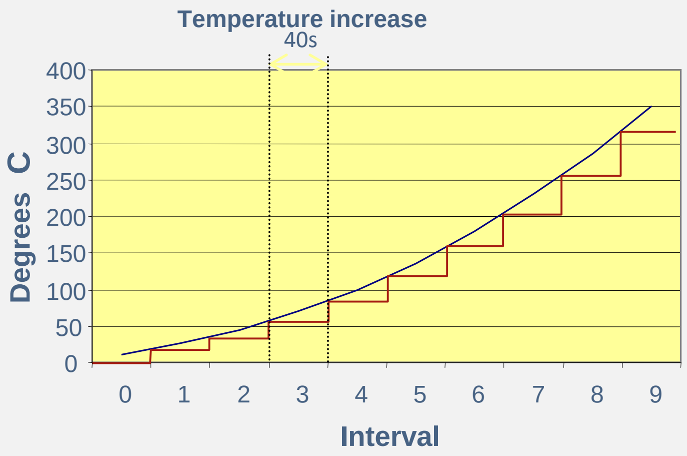


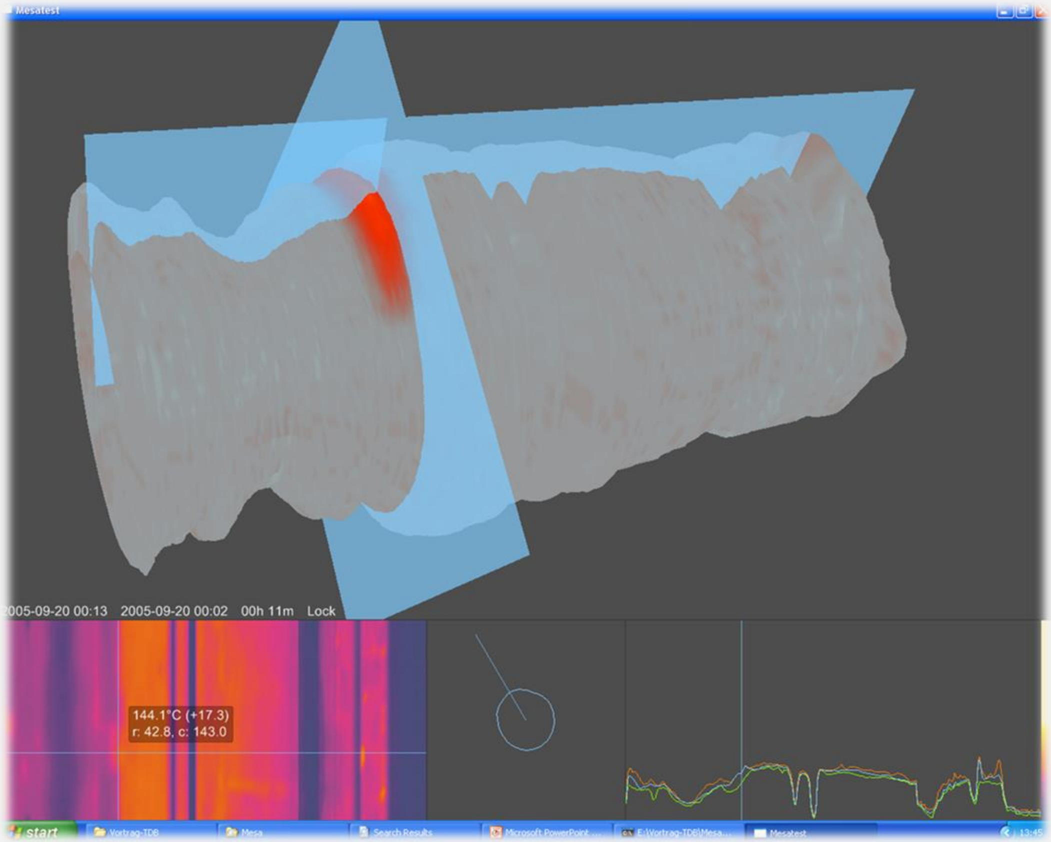
3D map



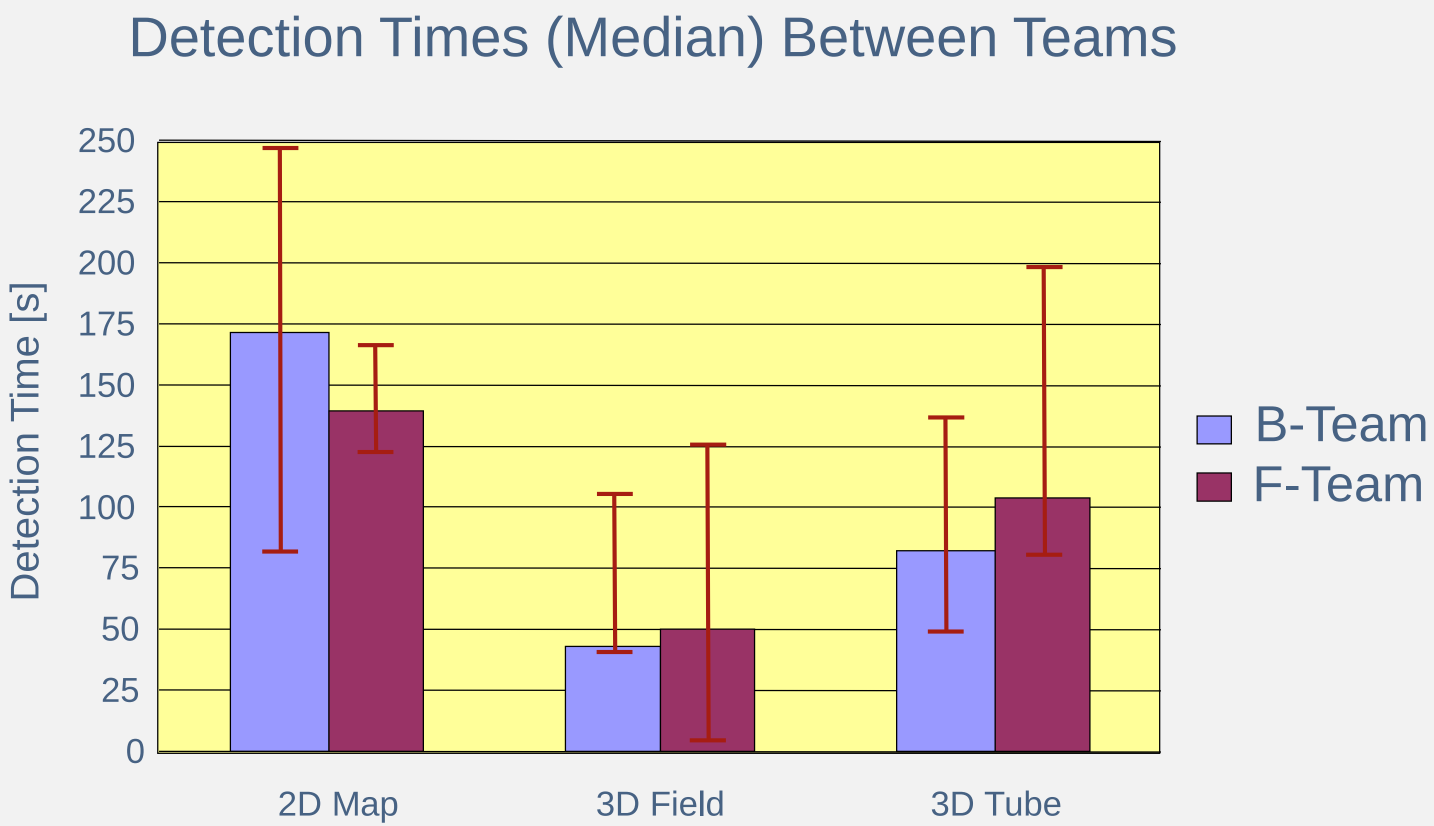
3D cylindrical

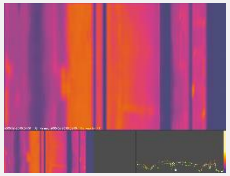
Validation study in the field

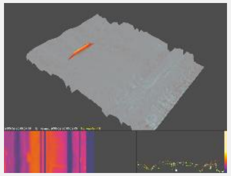


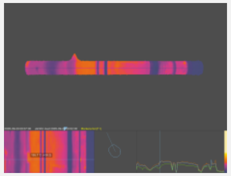


Some results









Visualization
Potential and pitfalls

Visualization has an enormous potential!

”An image tells more than thousand words”

But:

”The eye sees what it wants to see”

CAVEAT: Illusions and perceptual limits

Visualization
Ambiguous representations

”The eye sees what it wants to see?”

Sax player or woman's face?

Seal or donkey's face?

Bacchus or couple kissing?

How you interpret the visual percept depends among others things upon your personal attitude, expectations (context).

But visual angle is important, too!
Visual elements that subtend 4 degrees visual are most prominent.

Visualization
Cognitive limits

Visualizations have enormous potential!

”An image tells more than thousand words”

But:

”Human’s capacity for <u>attention</u> is limited”

Example: “Inattentional blindness” aka “perceptual blindness”

Inattentional blindness

Task : Count the passes of the black team in the following video!

Daniel Simons & Christopher Chabris

Visualization
Cognitive limits

Visualizations have enormous potential!

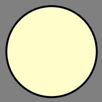
”An image tells more than thousand words”

But:

”Human short term memory (working memory) is limited”

Example: “Change blindness”

Change Blindness:



Change Blindness:

Visualization

Change Blindness:

Fairly large changes in a scene are not detected if they coincide with some visual disruption.
(e.g. saccades, blinks, transient noise and distraction)

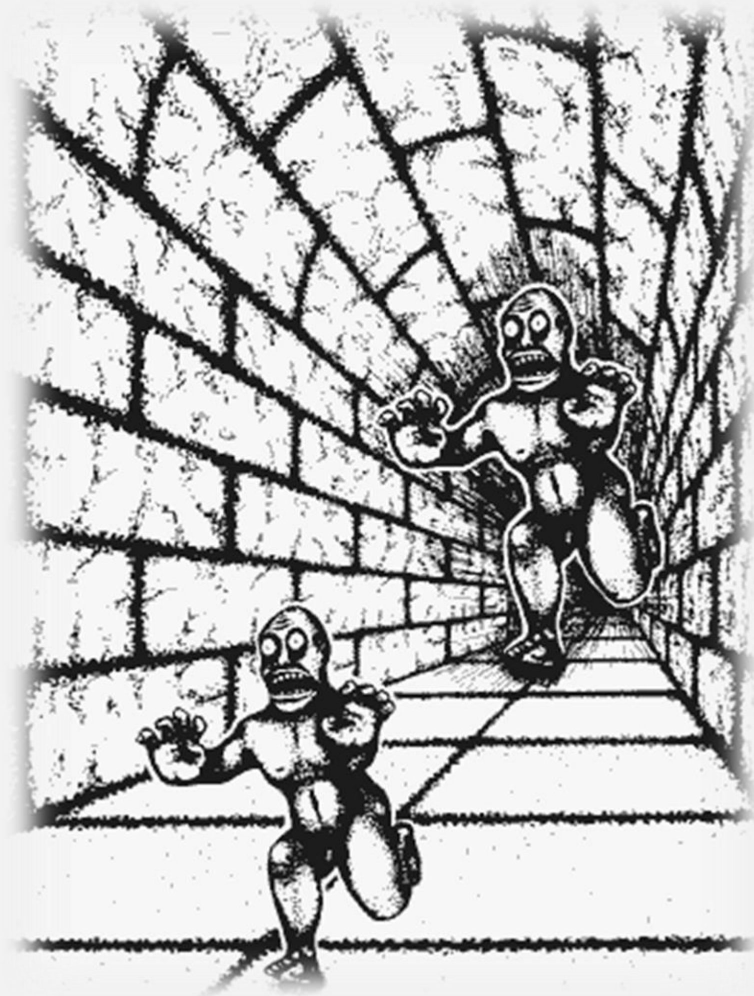
Failure to compare relevant visual information from current scene with visual short term memory.

Visualization
Potential and pitfalls

The visual percept of size
is not constant.

Retinal size of objects is does not
predict real size.

Example:
Mix of 2D spatial size and 3D
perspective cues



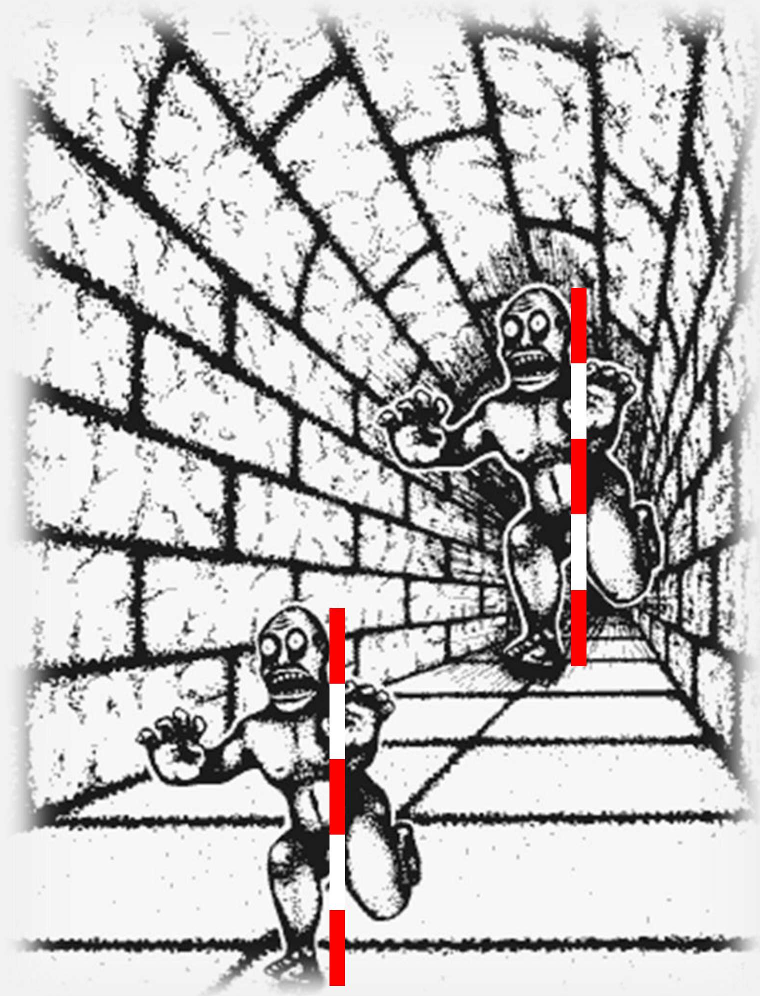
Visualization
Potential and pitfalls

The visual percept of size
is not constant.

Retinal size of objects is does not
predict true size.

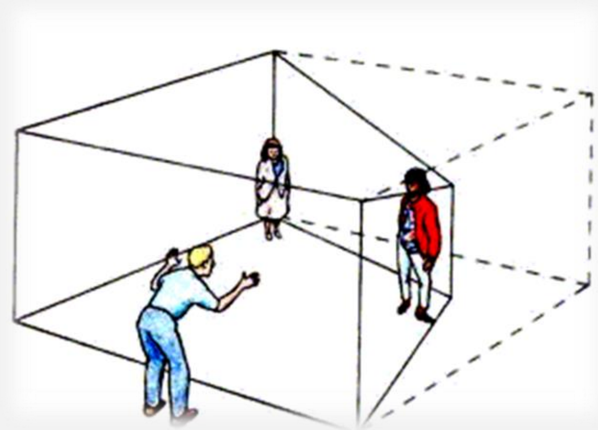
Example:
Mix of 2D spatial size and 3D
perspective cues

Beware of this when making
judgements of length/sizes in
mixed visualizations (2D/3D)
e.g. using 2D bars in 3D landscape



Visualization
Potential and pitfalls

Illusions from deliberately chosen inconsistent 3D cues (Ames Room)



By Adelbert Ames Jr. (Ophtalmologist), 1934;