CSE 612: Advanced Visualization

Lecture 1: Perception

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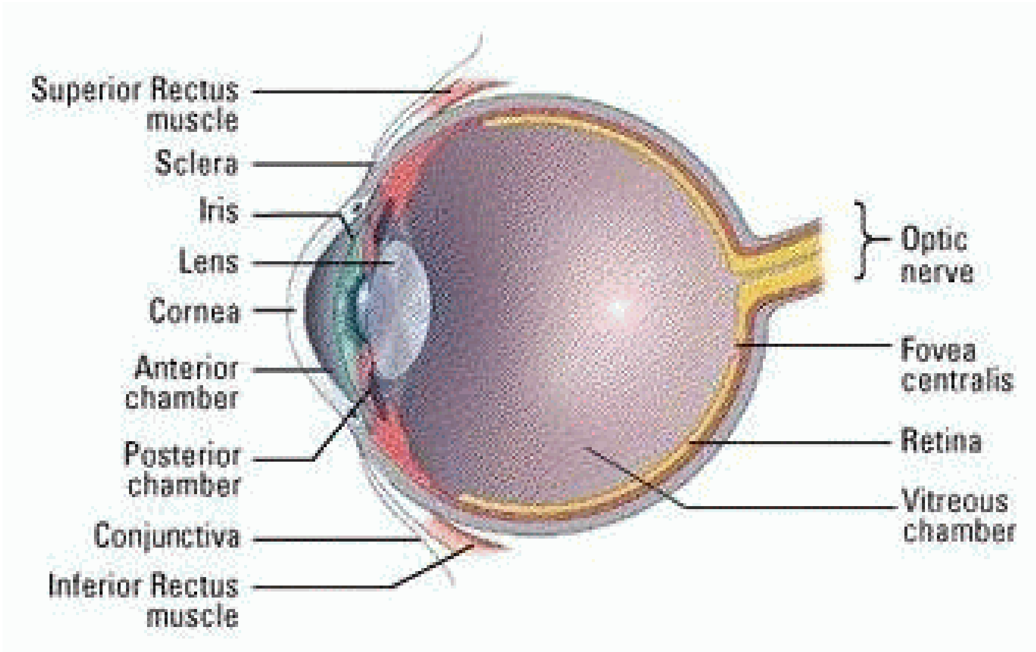
(with some material taken from presentations of

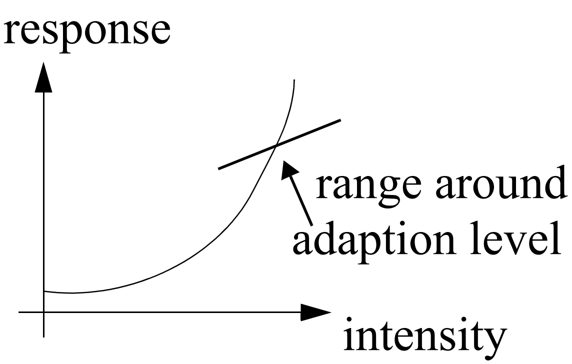
Profs. Colin Ware, University of New Hampshire, and Jürgen Döllner, University of Potsdam)

The Human Eye



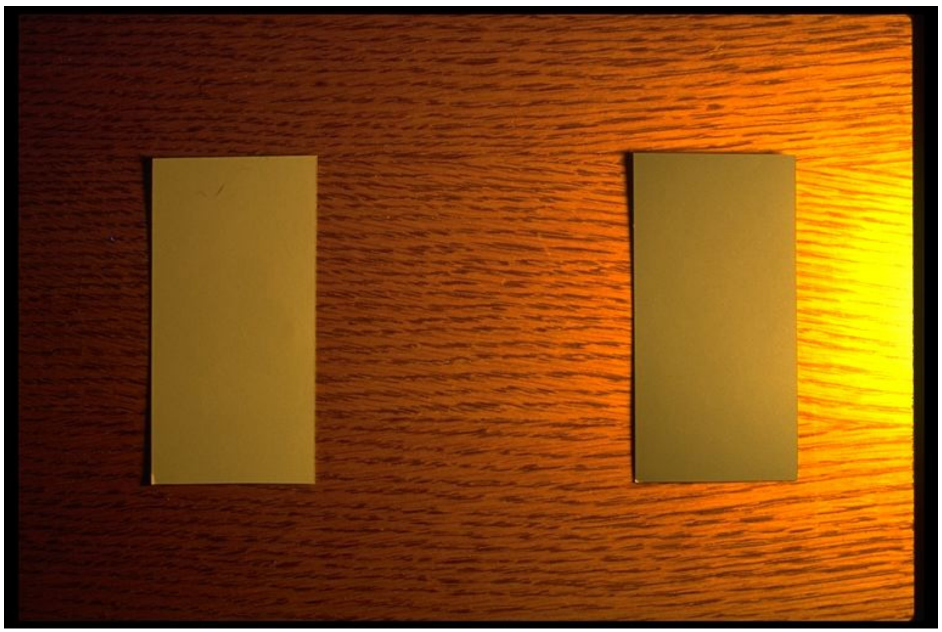
- Two types of receptors on retina: *rods* and *cones*
- Rods:
  - spread all over the retinal surface (75 - 150 million)
  - low resolution, no color vision, but very sensitive to low light (*scotopic* or dim-light vision)
- Cones:
  - a dense array around the central portion of the retina, the fovea centralis (6 - 7 million)
  - high-resolution, color vision, but require brighter light (*photopic* or bright-light vision)

Dynamic Range Contrast



- Although the eye can operate under a wide range of light intensities, it can only resolve a small contrast range at a given time.
- Adaption is required before switching to a different intensity range

Note the time needed to adapt to changing light conditions when stepping into a dark room



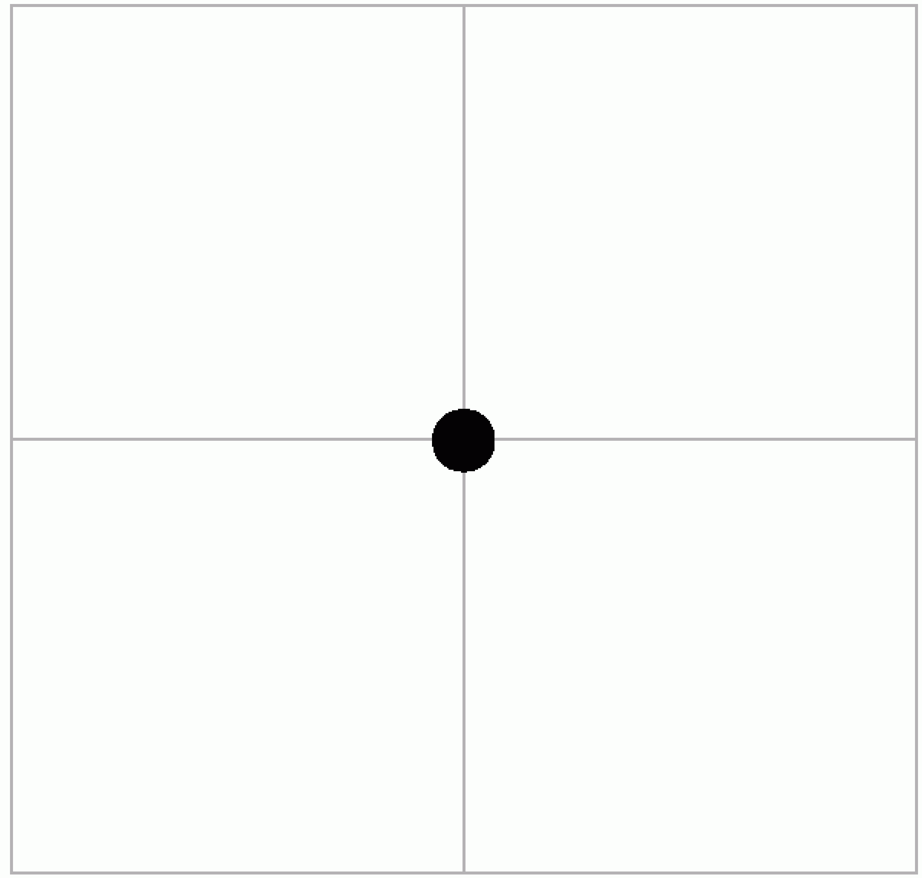
Local adaption level varies, which changes the relative contrast of the objects in the local scene

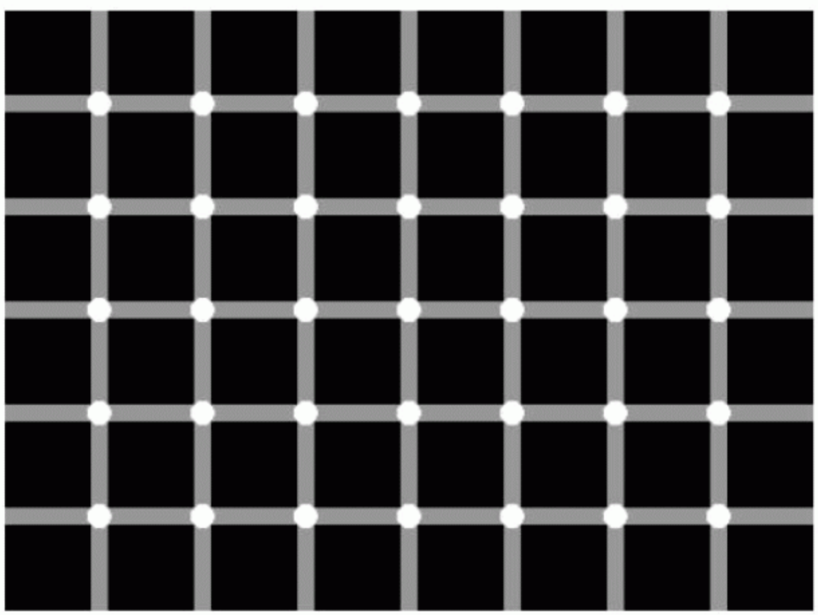
from: Colin Ware

Successive Contrast

Focus on the black circle for a few seconds, then switch to one of the white fields. For a moment, you will see a white circle (the complementary color to the black circle).

This is due to the local change of the adaption level.

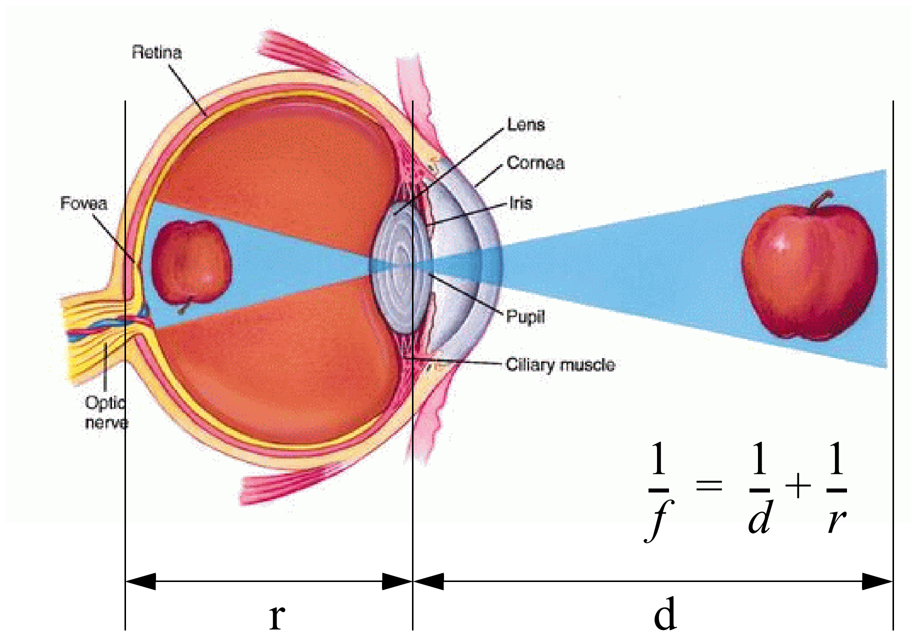




Another example.

from: Colin Ware

The Eye's Lens System



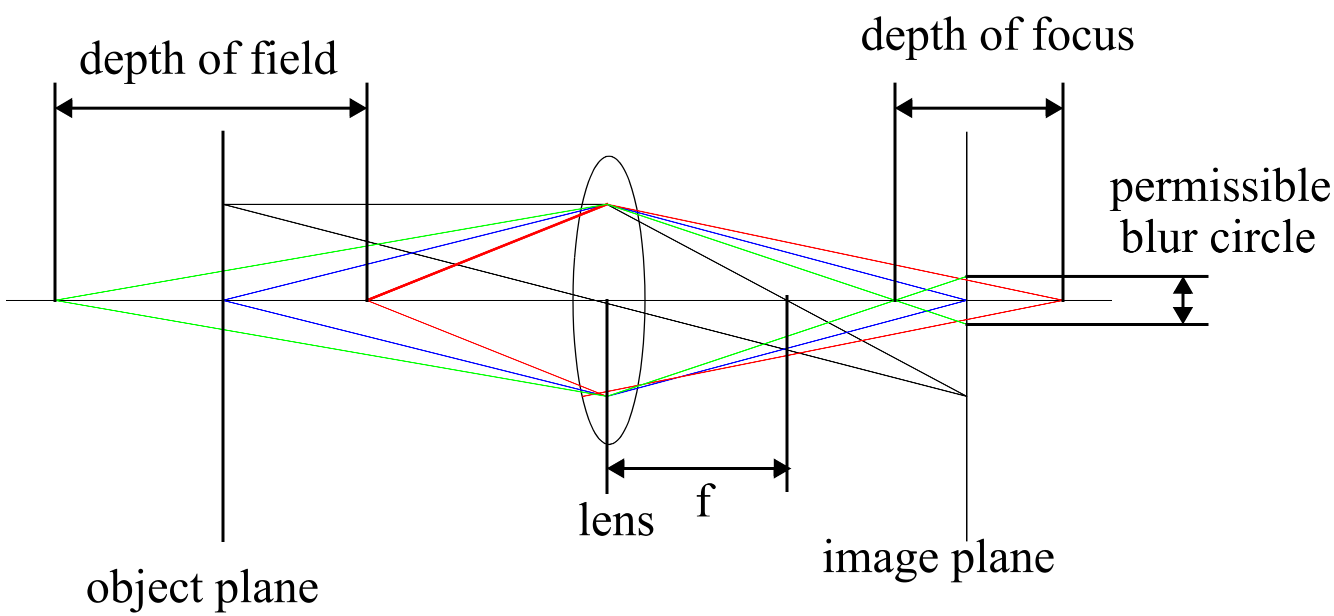
$$\frac{1}{f} = \frac{1}{d} + \frac{1}{r}$$

Depth of focus / field = distance over which objects are in focus without change in focus

Distance of focus varies with size of the pupil

Depth of focus at varying viewing distances:

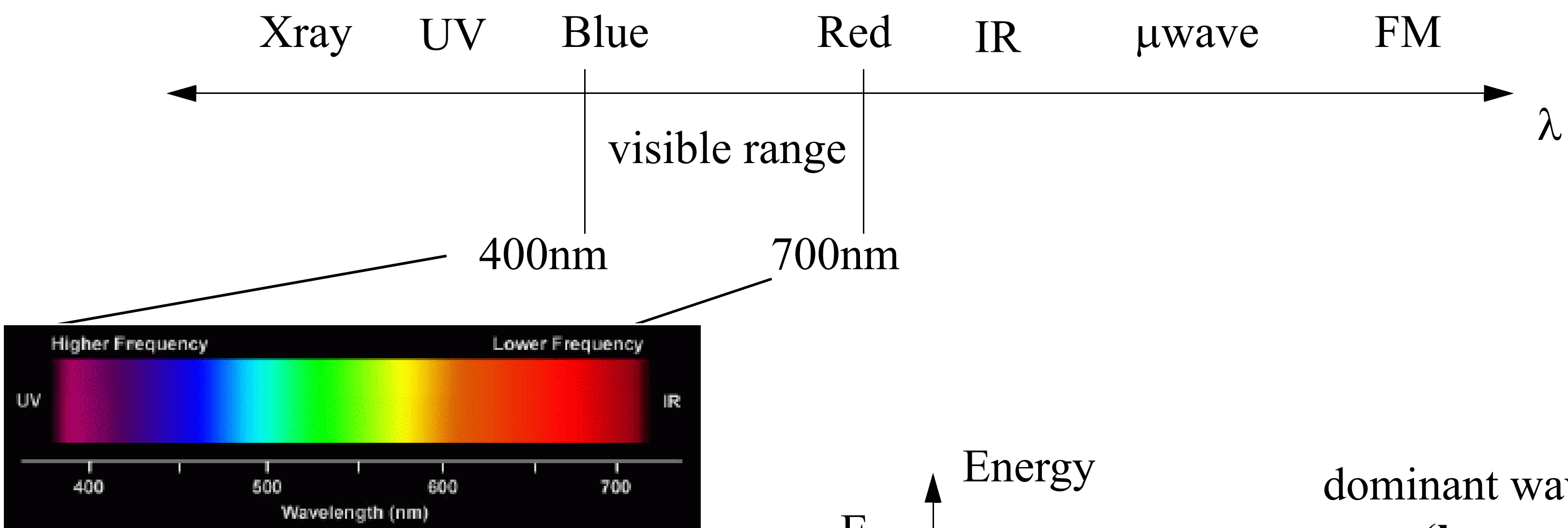
0.5 m	43 cm - 60 cm
1 m	75 cm - 1.5 m
2 m	1.2 m - 6 m
3 m	1.5 m - infinity



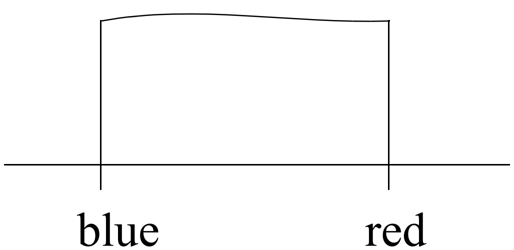
from: Jürgen Döllner

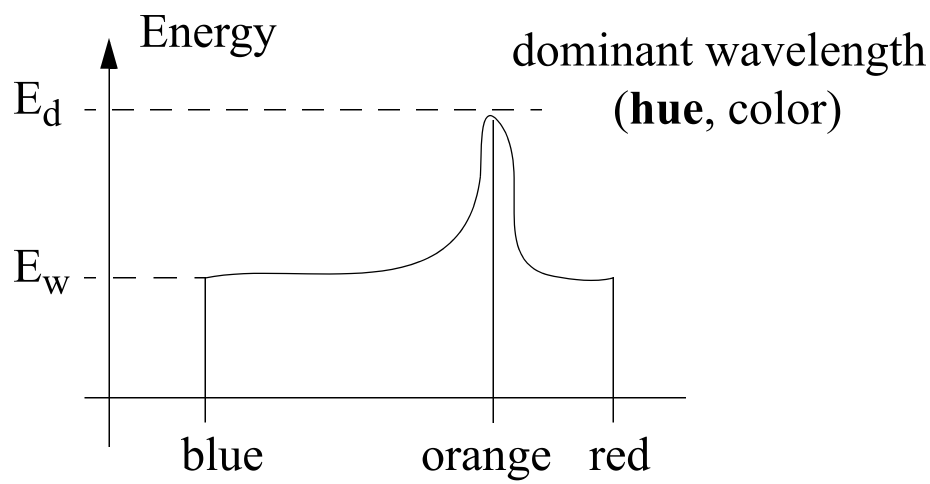
Color Definitions

Spectrum:



white light: all wavelengths





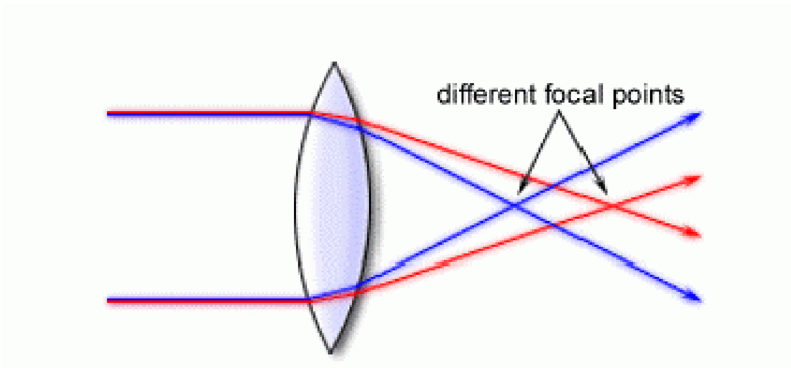
$E(\lambda)$: overall intensity = **brightness** or **luminance**

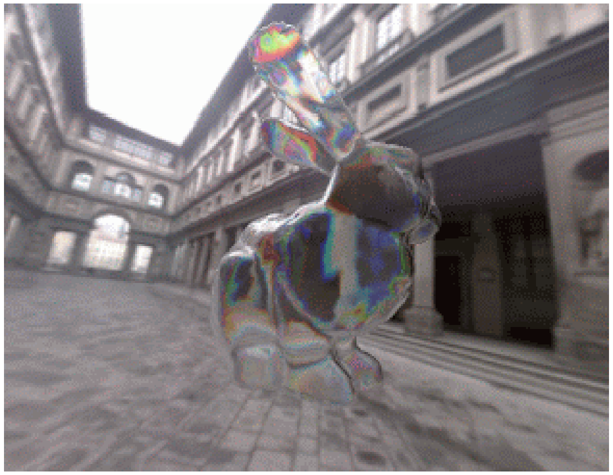
ratio of E_d vs. E_w = **saturation**

The human eye differentiates about 300 hues and 100-150 luminance variations

Chromatic Aberration

- Different wavelengths of light are focused at different distances within the eye
- Short-wavelength blue light is refracted more than long-wavelength red light
- Focusing on a red patch, an adjacent blue patch will be significantly out of focus
- The human eye has no correction for chromatic aberration
- Inadvisable: fine blue patterns in visualizations!
- Strong illusory depth effects
- Visual effects in soap bubbles, crystal sculptures, etc.

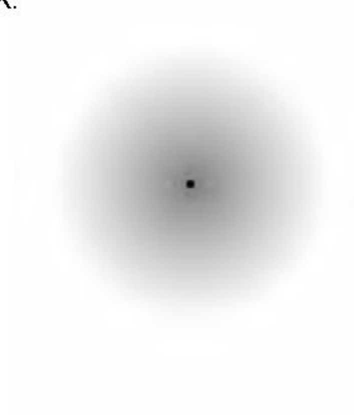


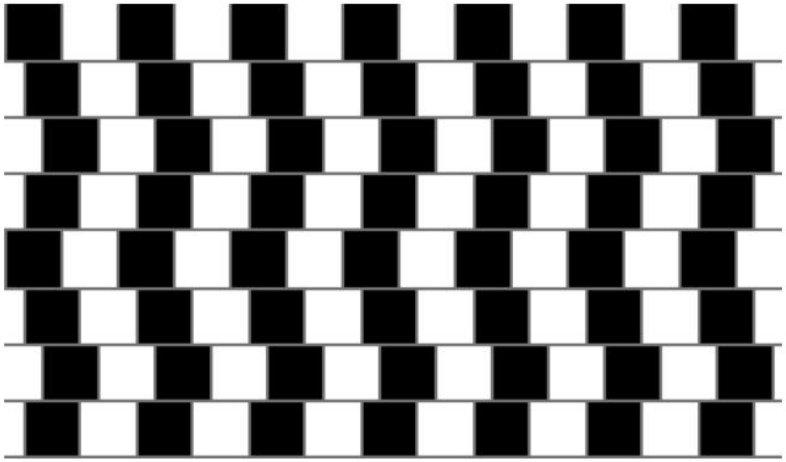


from: Jürgen Döllner

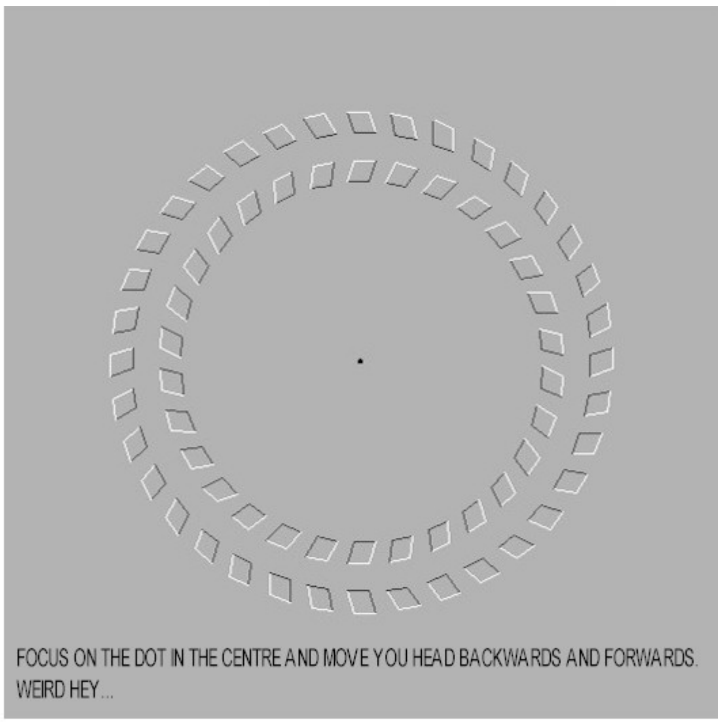
More Perception Trickery

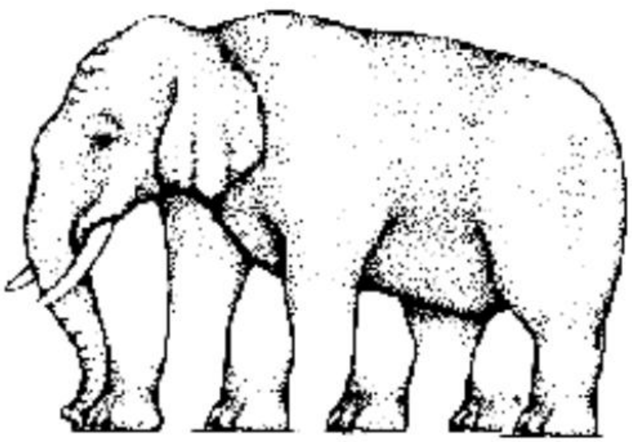
Keep staring at the black dot. After a while the gray haze around it will appear to shrink.





Are the horizontal lines parallel or do they slope?





How many legs does this elephant have?

- Example:

Look at the chart and say the COLOUR not the word

YELLOW BLUE ORANGE
BLACK RED GREEN
PURPLE YELLOW RED
ORANGE GREEN BLACK
BLUE RED PURPLE
GREEN BLUE ORANGE

Left – Right Conflict

Your right brain tries to say the colour but your left brain insists on reading the word.

from: Colin Ware

Pre-Attentive Processing (PAP)

- Limited set of visual properties that are processed pre-attentively, w/o need for focused attention
- Visual tasks performed on large displays in less than 200 - 250 msec are considered pre-attentive
- Experiment to test PAP: display test objects at random locations on a large display

  - ensures that attention cannot be pre-focused on any particular location

  - yet subjects report that recognition tasks can be performed with little effort

  --> certain information in the display is processed in parallel by the low-level visual system
- Benefits for visualization:

  - PAP tasks are *rapid* and *accurate*, take less than 200 ms at near-perfect accuracy

  - time to perform PAP tasks is independent of display resolution and size

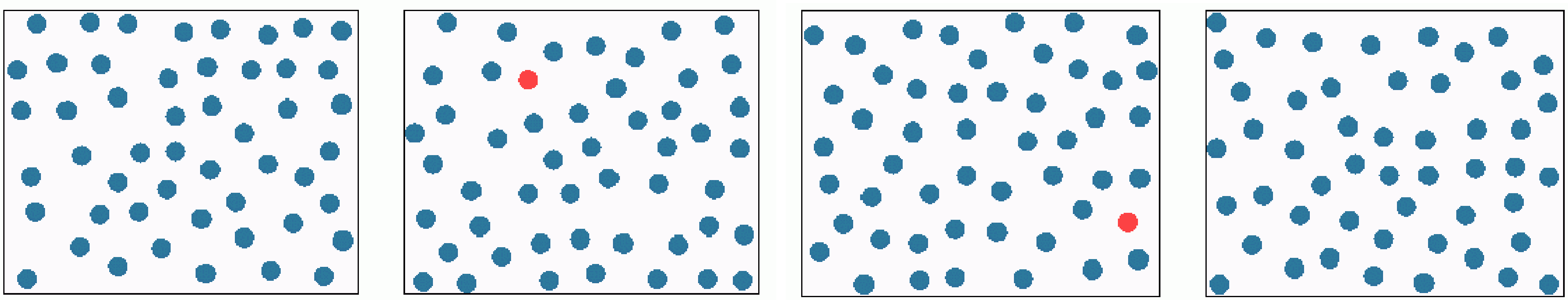
  - experiments for PAP can uncover how visual features interact with one another

  - can reveal feature preferences, masking effects, & the required amount of feature difference

  - tested visual tasks are: target detection, boundary detection, counting

Pre-Attentive Processing (PAP): Hue

- Pre-attentive task: Detect a red circle in a group of blue circles
  - search is based on different hue
- Results:
  - a viewer can tell at a glance whether the target is present or absent
  - rapid and accurate determination

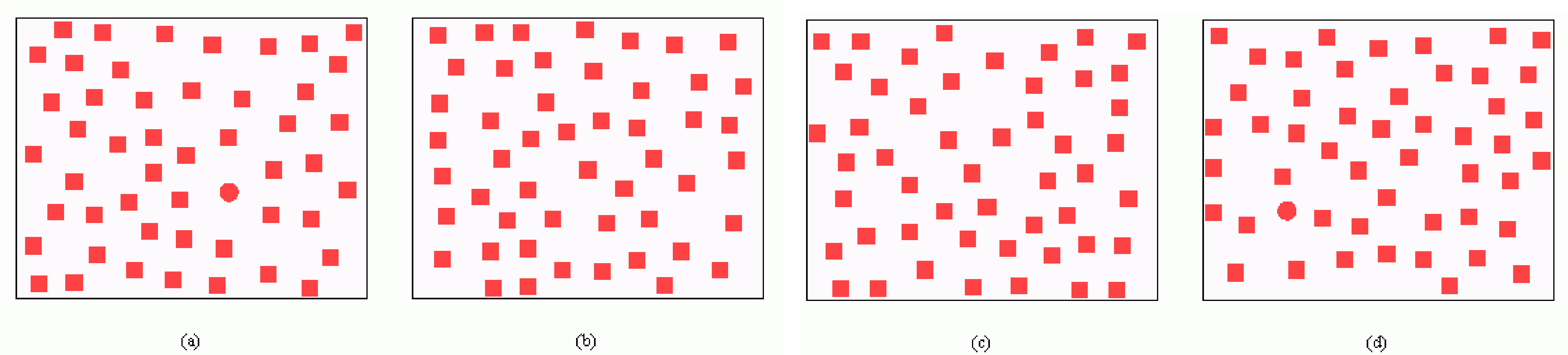


(a) (b) (c) (d)

from: Jürgen Döllner

Pre-Attentive Processing (PAP): Shape

- Pre-attentive task: Detect a red circle in a group of blue circles
  - search is based on different shape (of curvature)
- Results:
  - a viewer can tell at a glance whether the target is present or absent
  - rapid and accurate determination



from: Jürgen Döllner

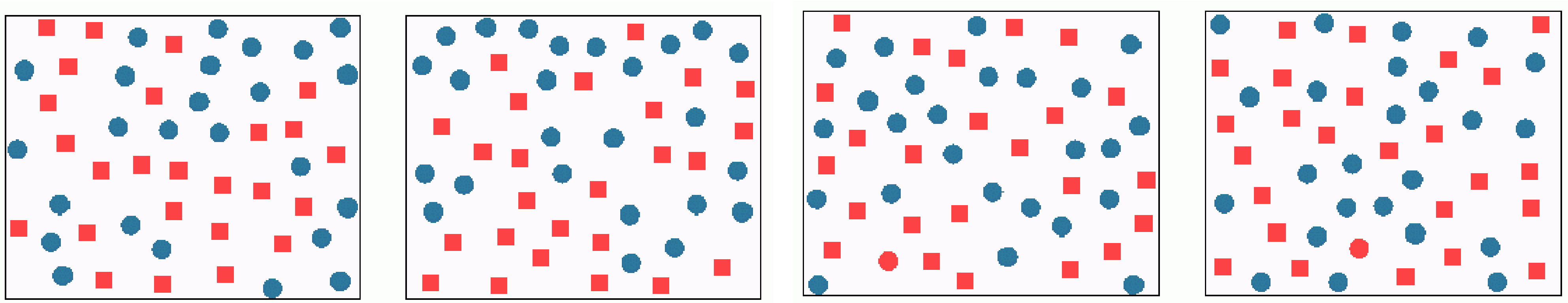
Pre-Attentive Processing (PAP): Conjunction

- Pre-attentive task: Detect a red circle in a group of blue circles

    - search for a conjunction target item (one that is composed of two or more features)

- Results:

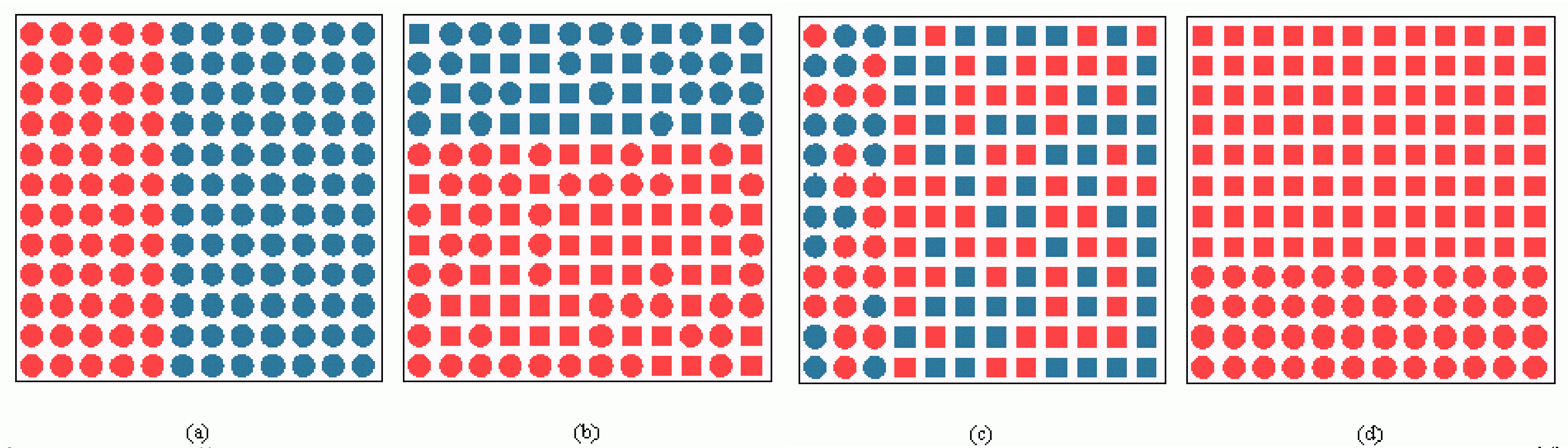
    - objects made up of a conjunction of unique features cannot be detected pre-attentively



(a) (b) (c) (d)

Pre-Attentive Processing (PAP): Visual Interference

- In (a) object shape is held constant (all circles) while in (b) shape varies randomly
  - experiments show that in both cases the orientation of the hue boundary (vertical or horizontal) can be pre-attentively identified
  - --> variation of shape has no effect of hue boundary identification
- In (d) hue is held constant, while in (d) hue varies randomly
  - if hue is held constant (d), the shape boundary is identified pre-attentively
  - if hue varies across the array (c), however, it is much harder to identify the boundary
  - --> random variation in hue masks the shape boundary users are trying to identify



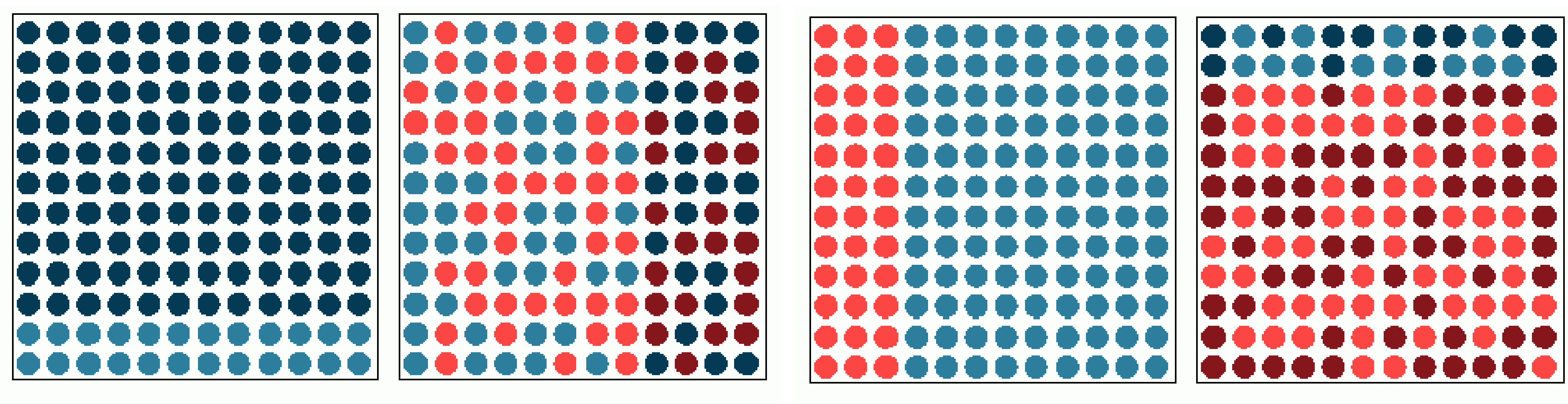
from: Jürgen Döllner

Pre-Attentive Processing (PAP): Intensity and Hue

- Random hue has no effect on detecting boundaries defined by itensity
- However, random intensity can interfere with (mask) hue boundary detection

  --> intensity is more important than hue to the low-level visual system for boundary ID

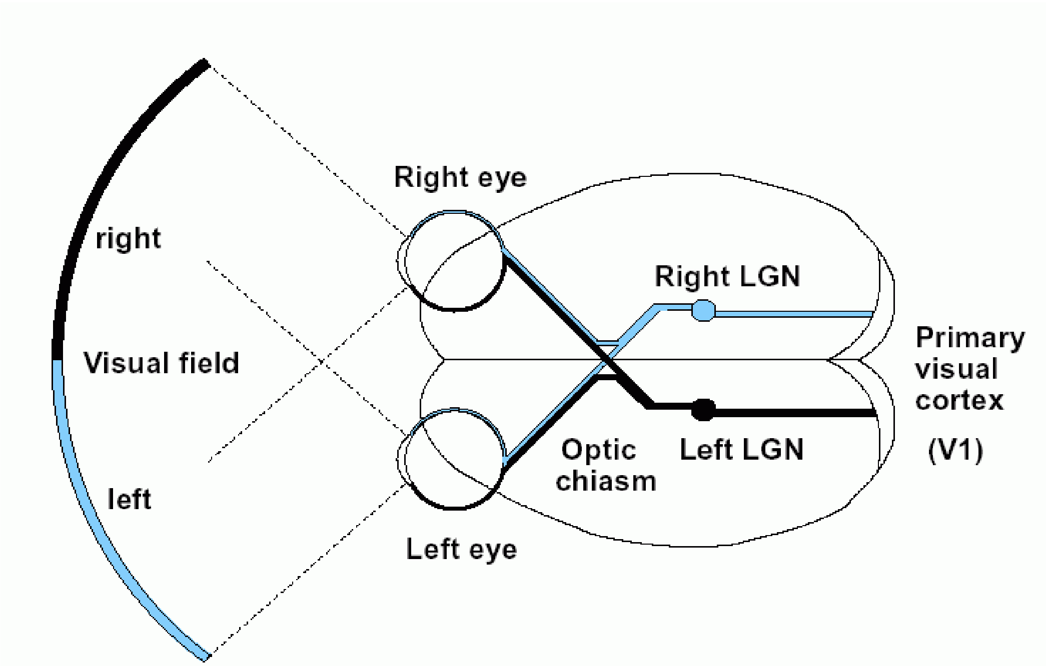
- (a, b): intensity boundary is pre-attentively detected, regardless of background hue patterns
- (c): hue boundary is pre-attentively detected with constant intensity
- (d) hue boundary is masked by a random intensity pattern

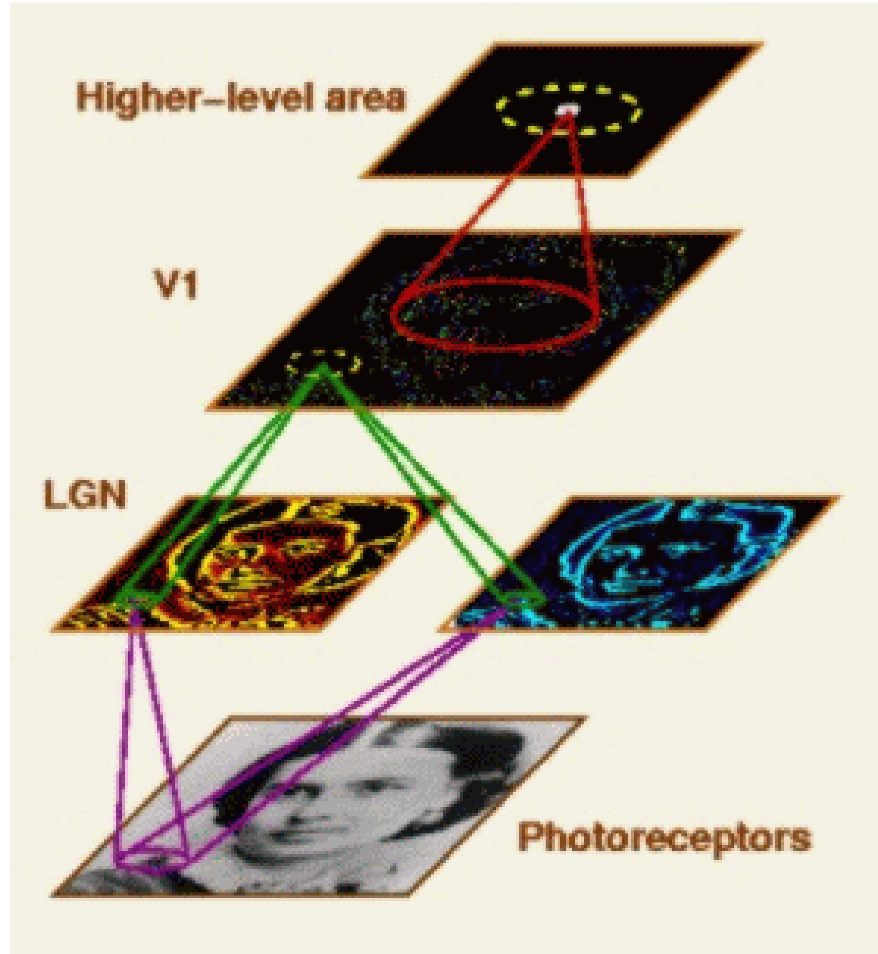


(a) (b) (c) (d)

from: Jürgen Döllner

Organization of the Human Brain





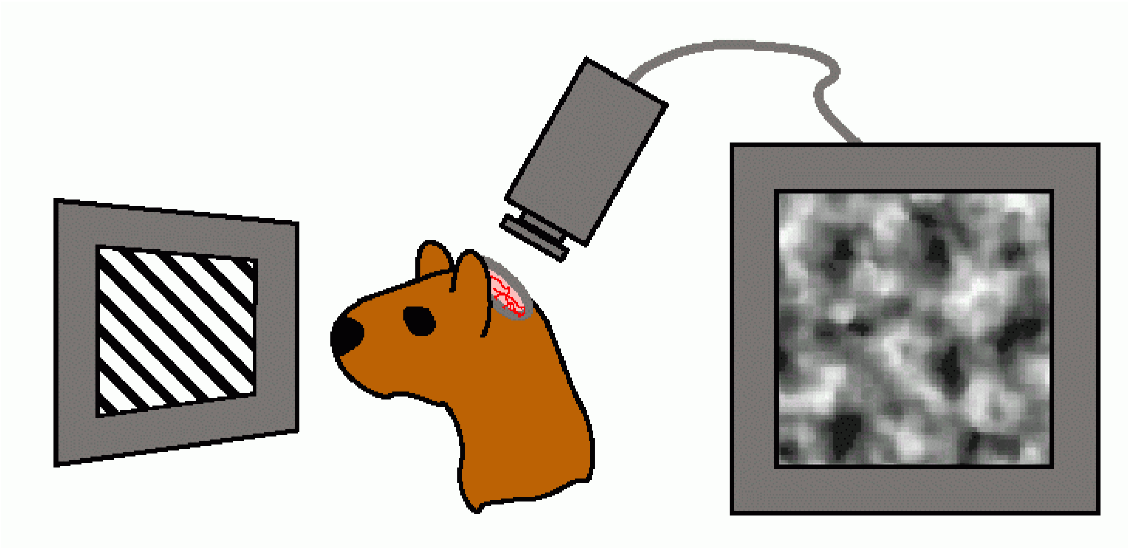
- LGN: left lateral geniculate nucleus of the thalamus
- V1: primary visual cortex

  - a quarter-sized area in the back of the head (the first cortical stage for most visual processing)

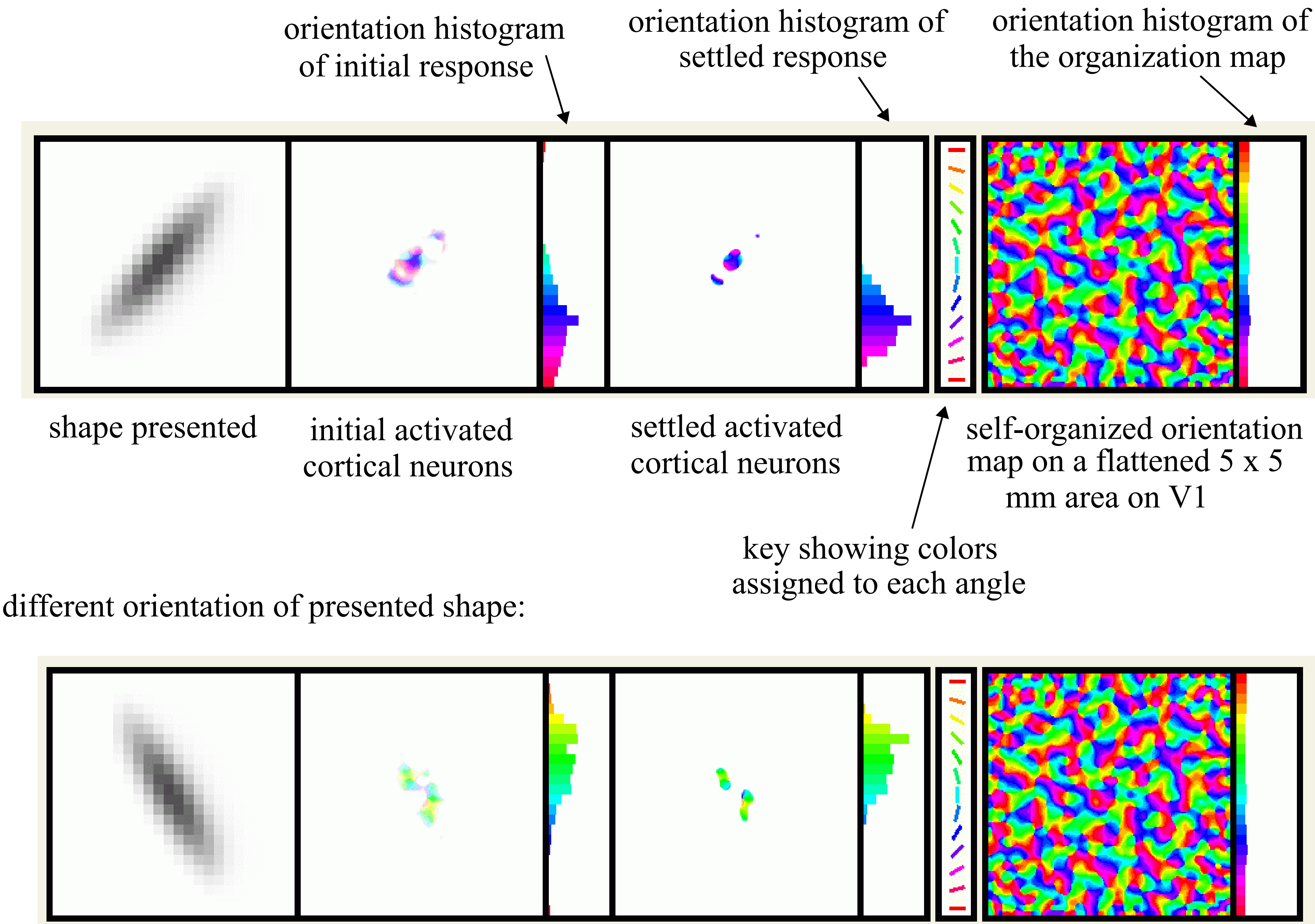
- Higher-level areas dedicated to spatial reasoning, associative object recognition, etc.

Measuring Orientation Maps

- Use optical imaging techniques to measure orientation preferences for a large number of neurons
  - remove part of the skull of a laboratory animal, exposing the surface of the visual cortex
  - present visual patterns to the eyes
  - a video camera records either light absorbed by the cortex or light given off by fluorescent chemicals applied to it
  - compare measurements between different stimulus conditions (orientations, temporal, etc)
- See *Topographica* software by Miikkulainen, Bednar, et. al. at University of Texas, Austin
  - java demos available at: http://www.cs.utexas.edu/users/jbednar/demos.html

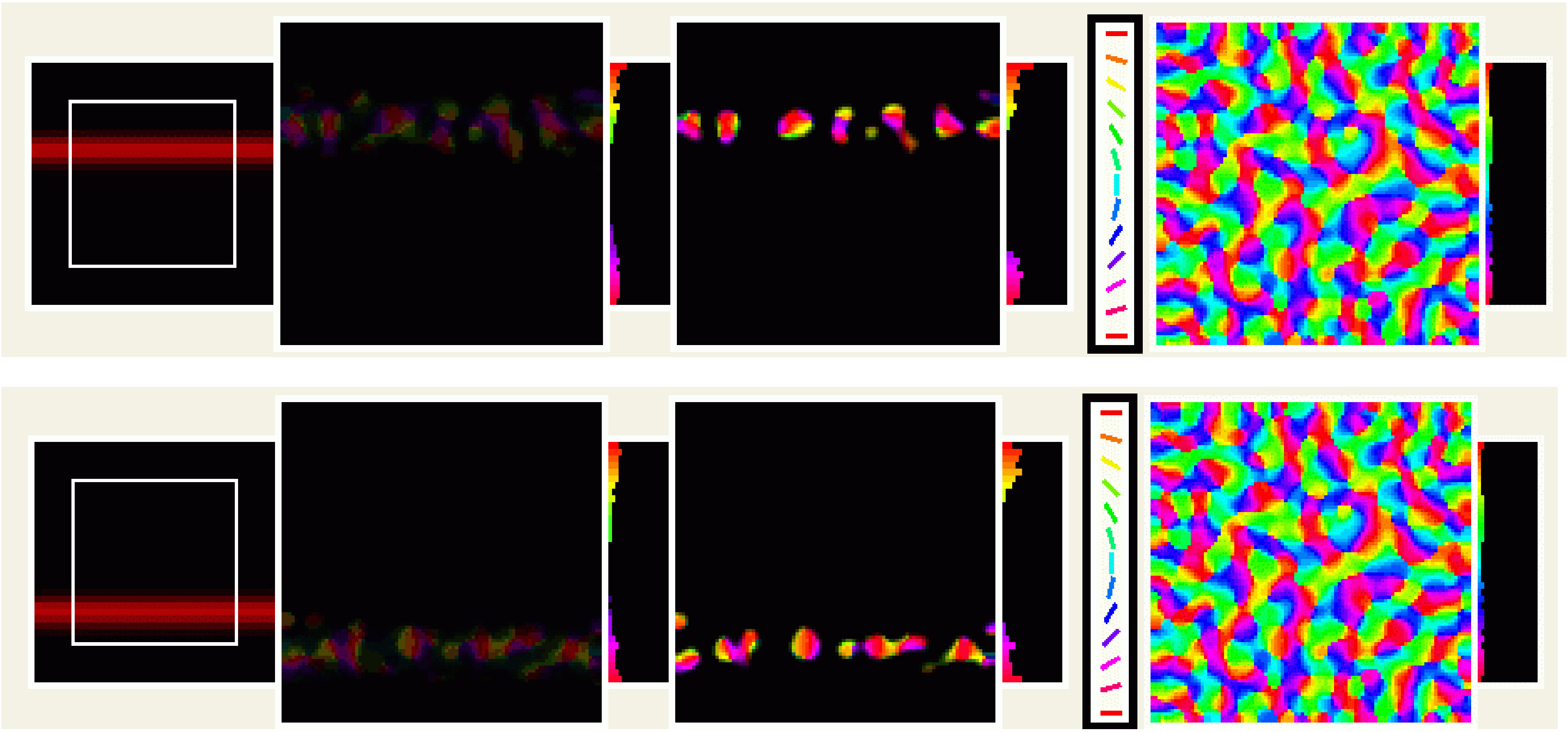


Organization and Sensitivity of the Visual Cortex

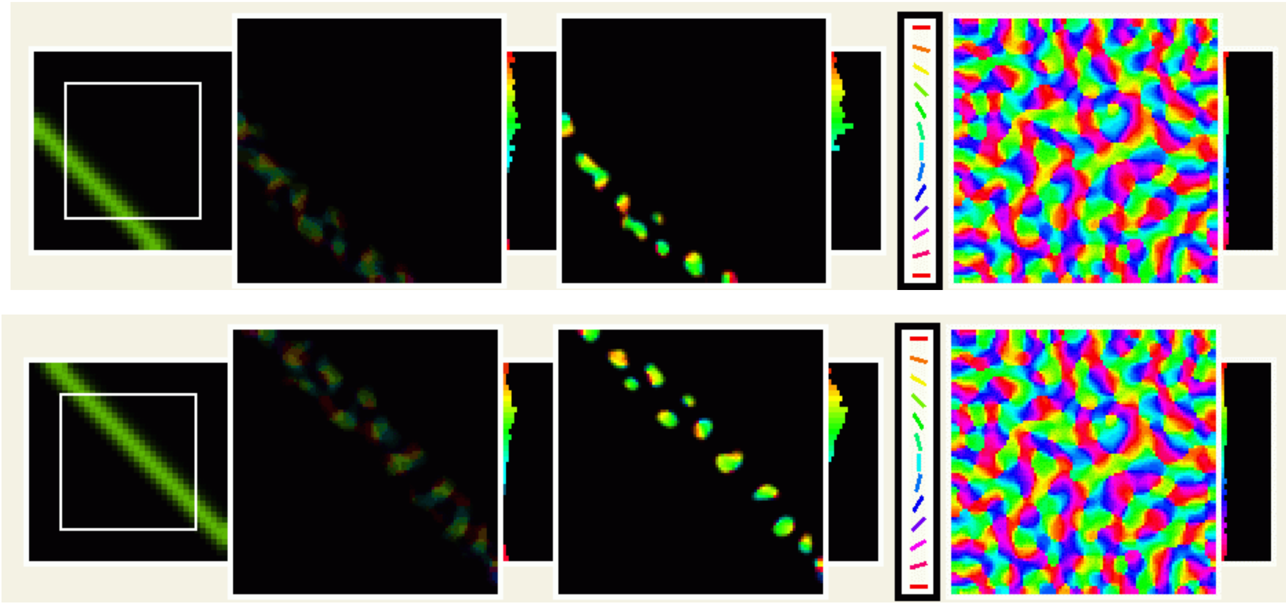


Organization and Sensitivity of the Visual Cortex

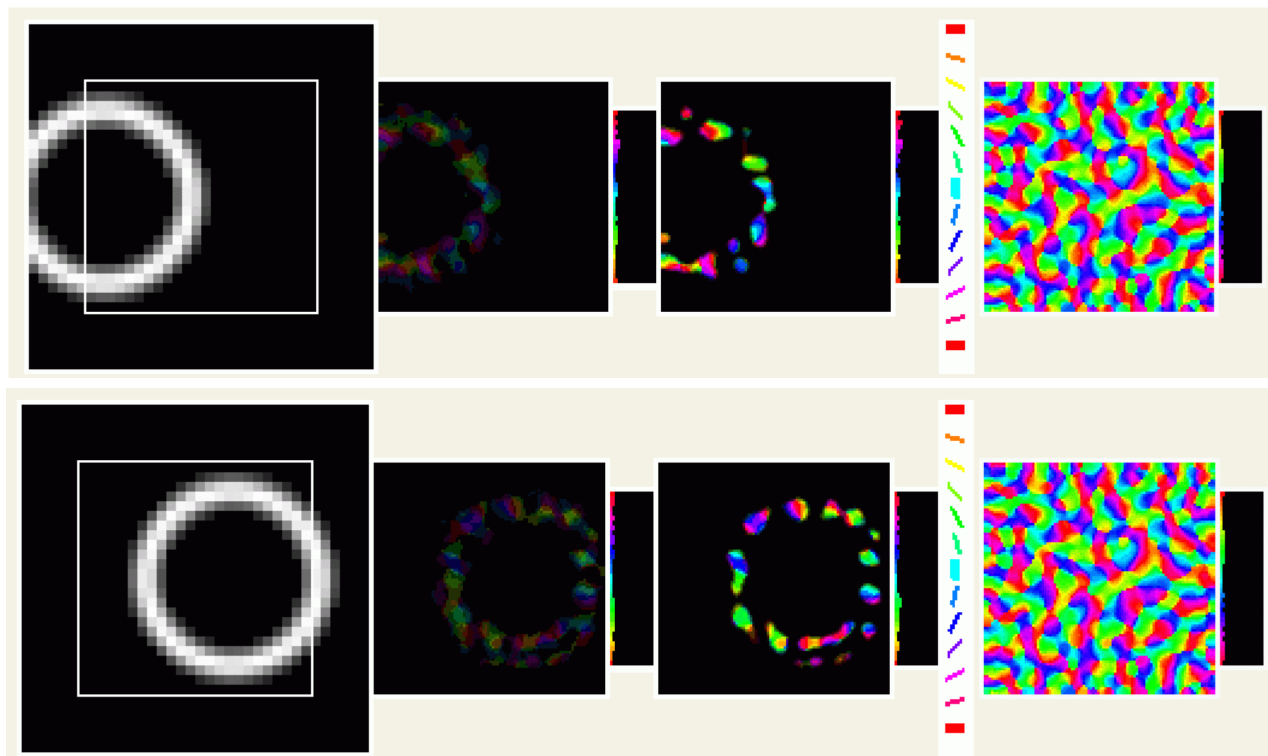
- Brain is sensitive to edges (contrast in intensity and color), pre-attentive
- Some more example obtained using *Topographica:*



Organization and Sensitivity of the Visual Cortex



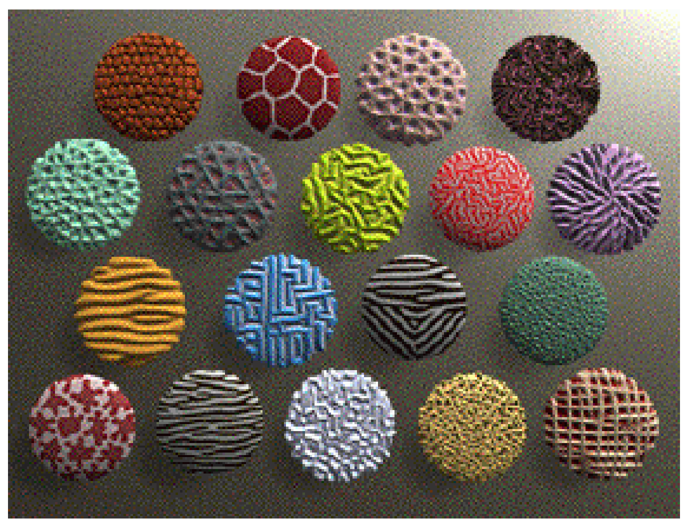
diagonal line

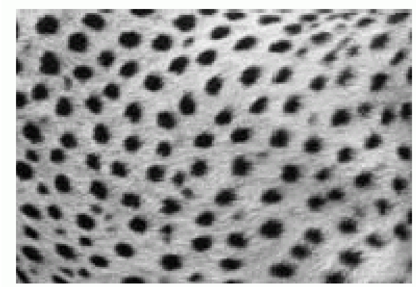


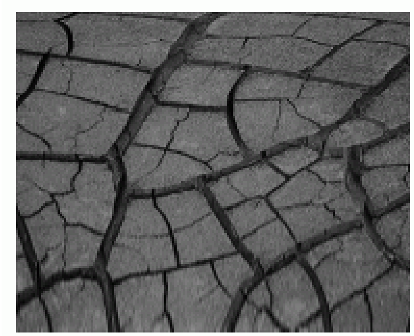
circle

Pre-Attentive Cues With Textures

- A visual texture represents that visual sensation that allows us to pre-attentively differentiate two adjacent, possibly structured parts in our visual field without eye movement
  - visual textures include micro-structures, patterns, profiles, etc.
  - to identify textures, an observations of about 160-200 ms is sufficient (cognitively controlled processes require about 300-400 ms)
- Classification of textures is based on
  - coarseness, contrast, directionality, line-likeness, regularity, roughness
- Textures improve perception of position and orientation
- Texture communicate information about the 3D structure regardless of their coloring



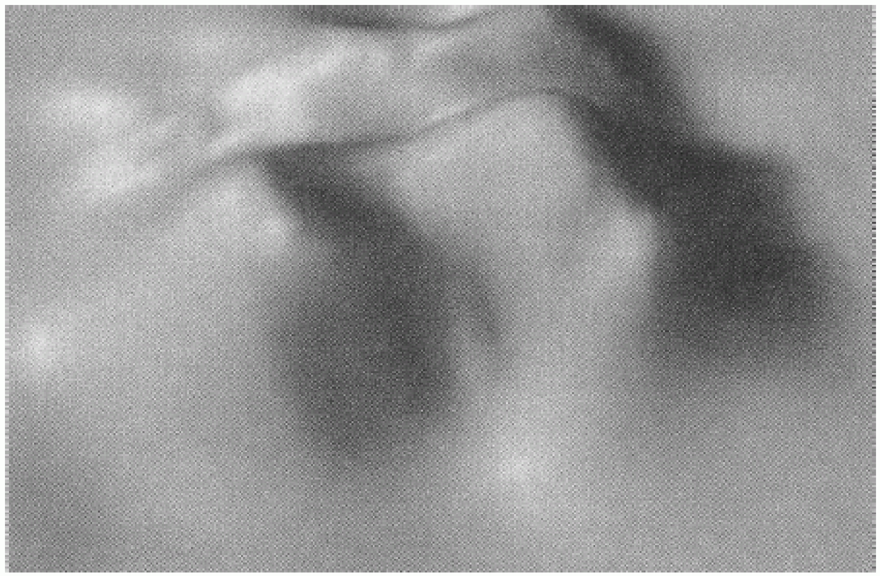


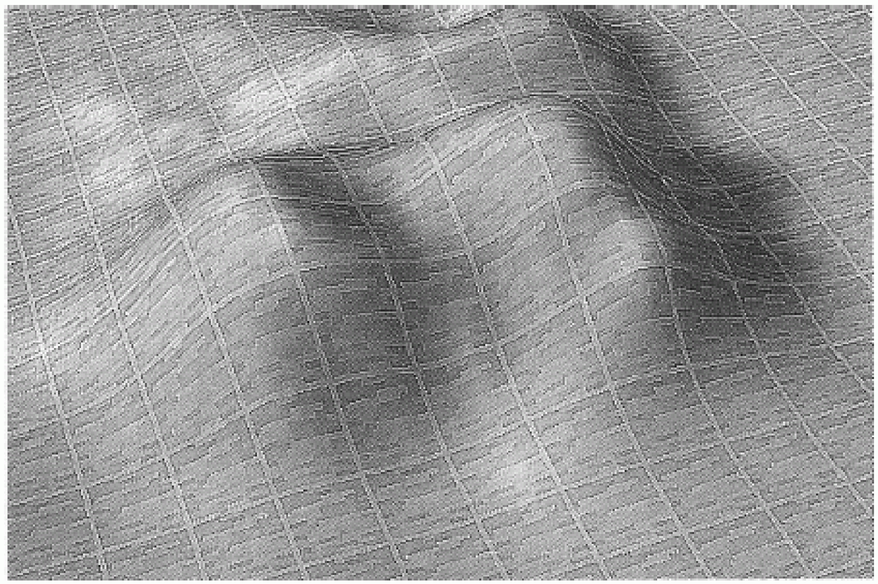


from: Jürgen Döllner

Pre-Attentive Cues With Textures

- Same surface with and without texture





- Textures that do not include information are to be avoided in visualization

    - recall Tufte's aesthetic principle that irrelevant decoration (= chart junk) should be avoided

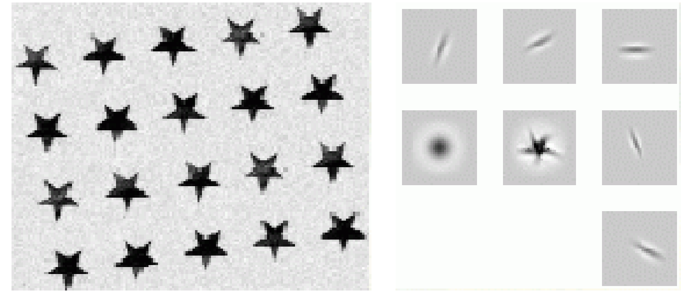
- Subtle textures for 3D visualizations, however, can be important elements of visual design

    - see above

from: Colin Ware

Texture Perception

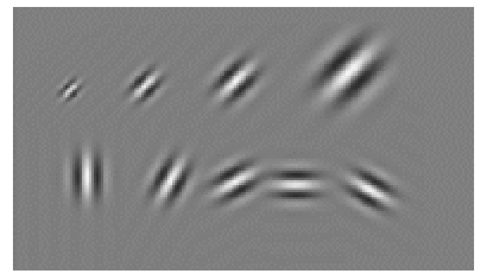
- *Textons*
  - fundamental micro-structures in generic natural images
  - basic elements in pre-attentive visual perception



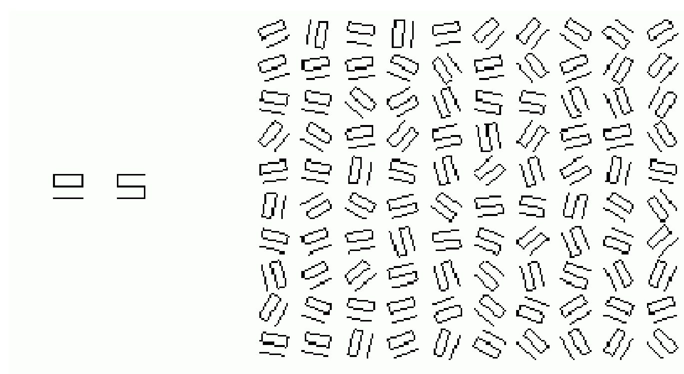
objects their textons

- Textons can be classified into three general categories:
  1. elongated blobs (line segments, rectangles, ellipses) with specific properties such as hue, orientation, and width, at different level of scales
  2. terminators (end of line segments)
  3. crossings of line segments

Gabor primitives



- Recall the sensitivity of the neurons in V1
- Julesz believes that only a difference in textons or in their density can be detected pre-attentively
  - no positional information about neighboring textons is available without focused attention
  - pre-attentive processing occurs in parallel (fast!)
  - focused attention occurs in serial (slower!)
- Example: although the two objects look very different in isolation (a), they are actually the same texton (b):



(a) (b)

from: Jürgen Döllner

Relation to Symbol and Texture Design

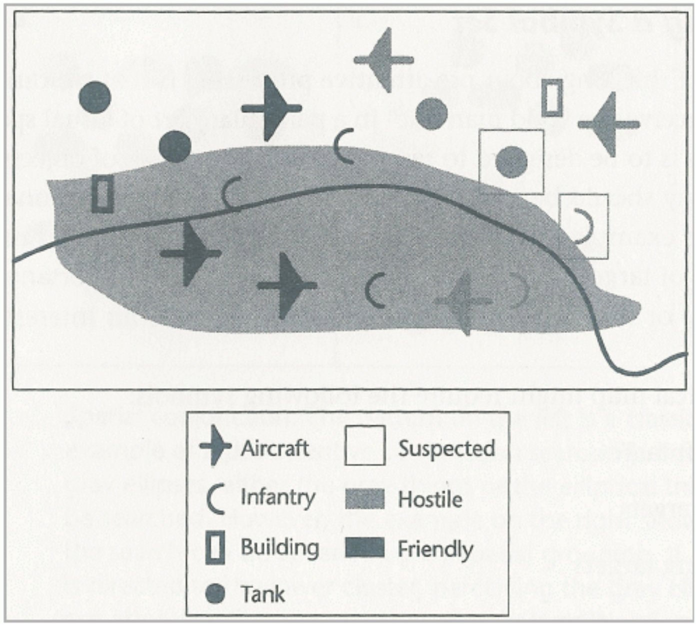
- When designing textures to indicate different regions of a visualization, make sure that the textons are as different as possible
- The same rules apply when designing symbol sets
- Example: A tactical map may require the following symbols:

  - aircraft targets

  - tank targets

  - building targets

  - infantry position targets



- Each of these target types can be classified as *friendly* or *hostile*
- Targets exist whose presence is suspected but not comfirmed (this uncertainty must be encoded)
- Set of symbols designed to represent different classes of objects

  - symbols should be as distinct as possible with respect to their pre-attentive processing

  - recall: military reconnaissance must occur FAST!

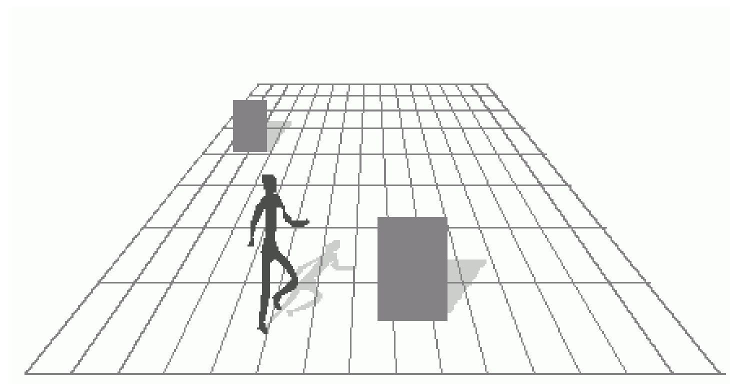
Information Display in 3D: Depth Cues

- 3D display should provide *depth cues*
- Linear perspective:

  - more distant objects become smaller in the image

  --> can indicate focus, importance, or ordering

  - elements of a uniform texture become smaller with distance --> can give shape cues



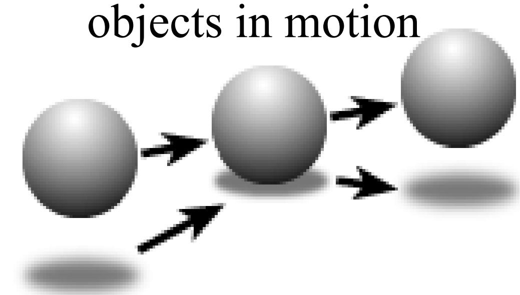
- Shadows:

  - show the relative height of objects above a surface

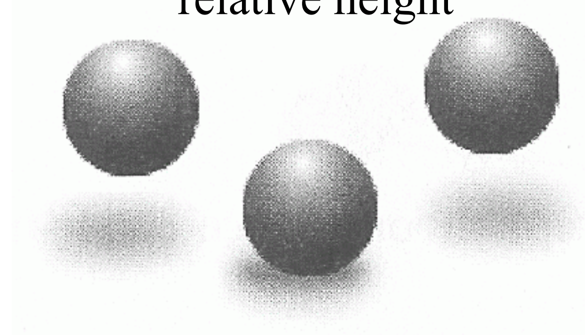
  - provide strong depth cues for objects in motion

  - can be semi-realistic and still work as a depth cue

objects in motion

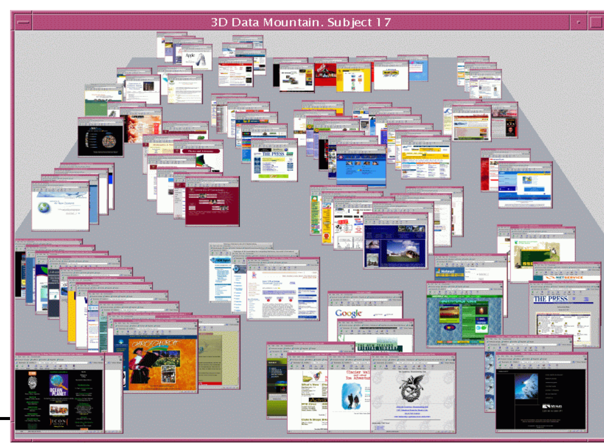


relative height



- Occlusion:

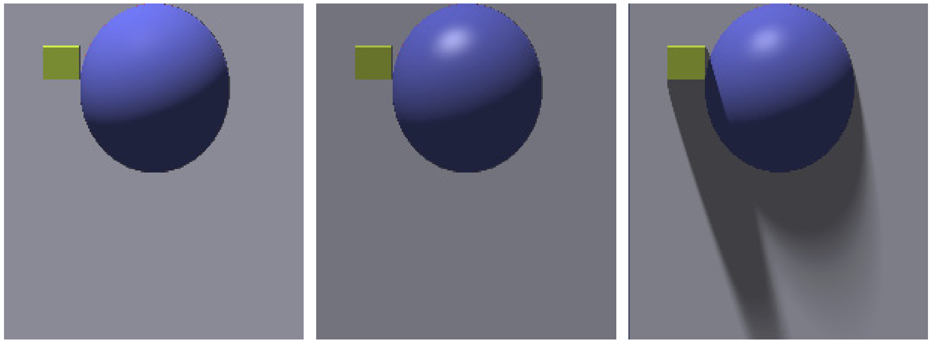
  - very powerful depth cue



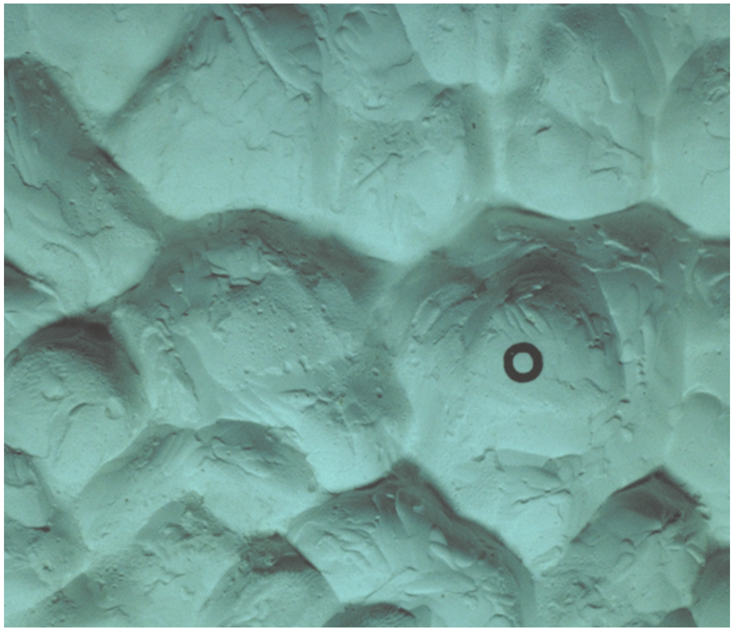
from: Colin Ware

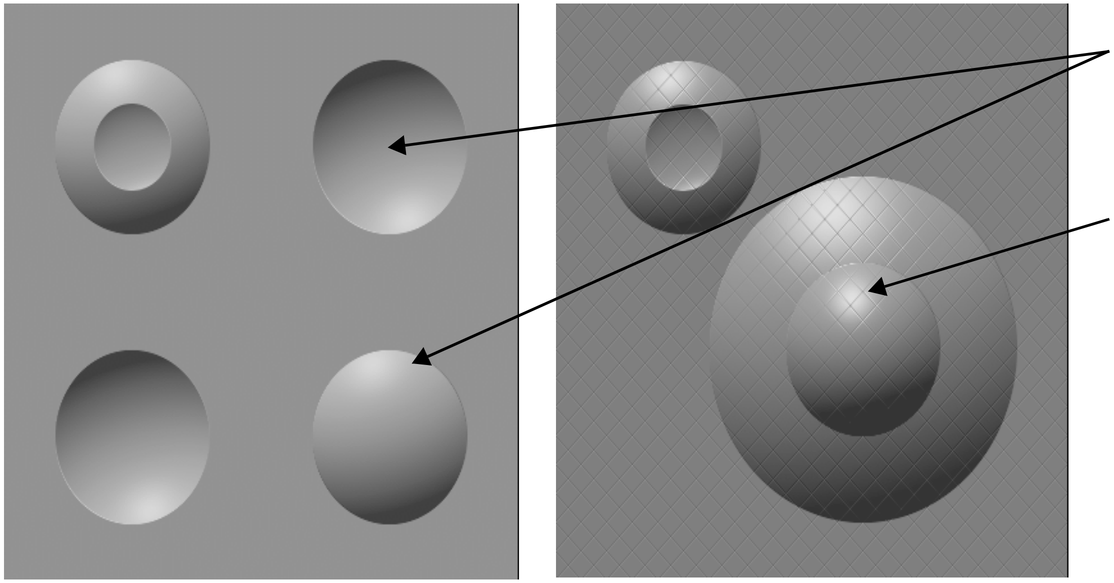
Information Display in 3D: Depth Cues

- Shading:
  - shape cues from shading (*shape-from-shading*)



diffuse + specular + shadows





shape from shading
(hole vs. hill)

specular can reveal fine detail

assume single light source

having more than one light source can lead to confusion

from: Colin Ware

Information Display in 3D: Depth Cues

- Other depth cues:

  - depth of focus

  - motion parallax (structure from motion) --> how objects relate under motion

  - steroscopic depth (binocular displays)

- For fine-scale judgement, for example, threading a needle:

  - stereo is important, and shadows and occlusion

- For large-scale judgement

  - linear perspective, motion parallax, and perspective are important

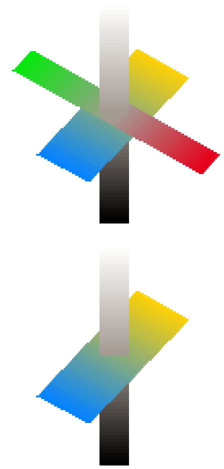
  - stereo is not so important

Color Perception

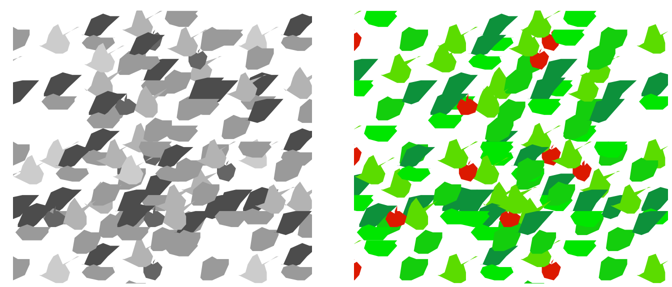
- Color resolution
  - the human eye differentiates about 300 hues and 100-150 luminance variations
  - best resolution is for green and red, less resolution for blue
- Color response
  - the time to response to a signal varies according to the color used
  - color ranking (from best to worst): yellow > white > red > green > blue
  - important features should be visualized in light colors, such as yellow and white
  - background information is best visualized in dark colors, such as green and blue
- Channel properties:
  - luminance channel: detail, form, shading, stereo, motion
  - color: surfaces of things, labels, categories (about 10)
  - red, green, blue, yellow are special (unique hues)

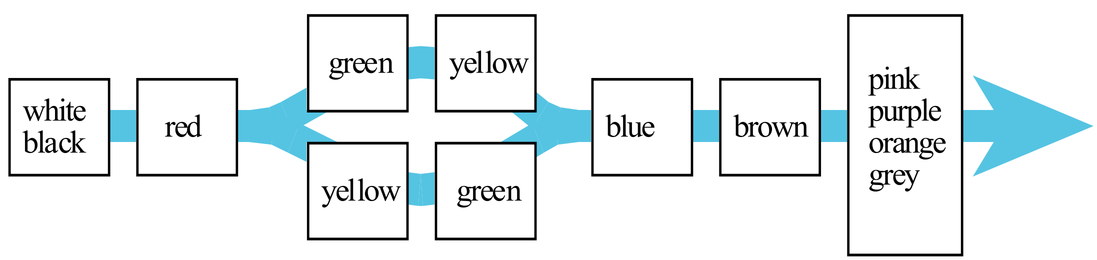
- Chromatic channels have low resolution
  - luminance contrast needed to see detail (3:1 recommended, 10:1 for small text)

Color Perception



- Color blindness
  - a 3D to 2D space
  - 8% of males is R-G color blind
  - Y-B variation is OK
- Color resolution
  - color perception is relative
  - we are sensitive to small differences --> hence need millions of colors
  - but we are not sensitive to absolute colors --> hence we can only use < 10 colors for coding
- Color is very helpful for classification tasks
  - color aids in rapid visual segmentation
  - color helps to determine type
  - only about 6 categories

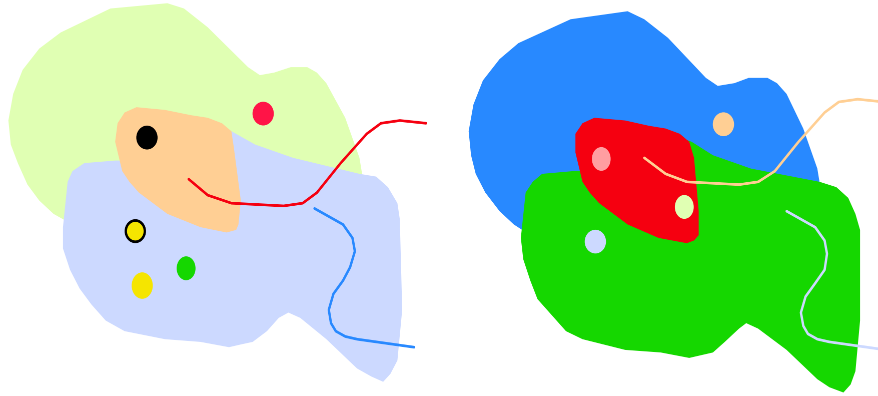




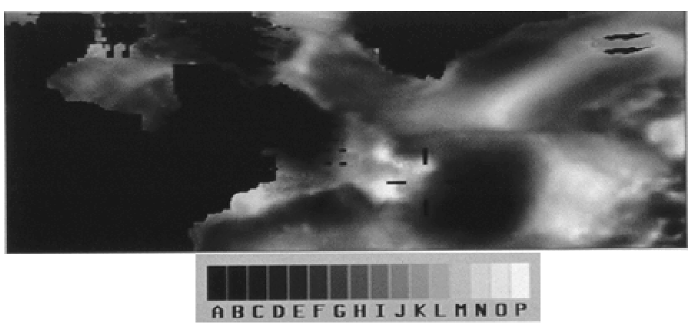
from: Colin Ware

Color Perception

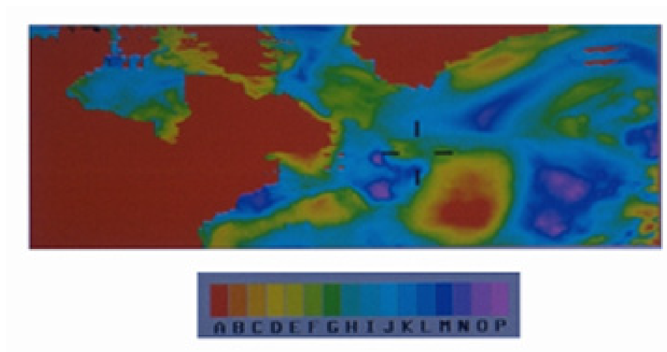
- Color coding
  - large areas: low saturation
  - small areas: high saturation
  - maintain luminance contrast
  - break iso-luminances with borders



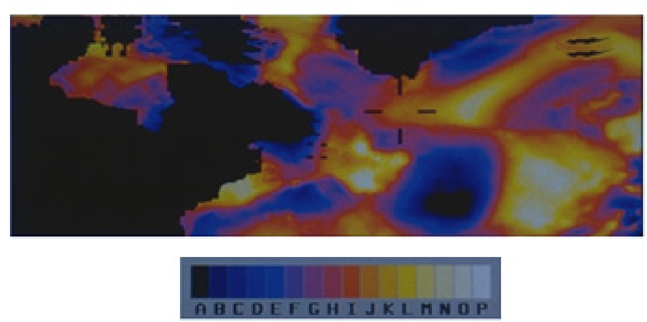
- Pseudo-coloring: assign colors to grey levels by indexing the grey levels into a color map



original greylevel map



simple spectrum sequence with iso-luminance



more effective:

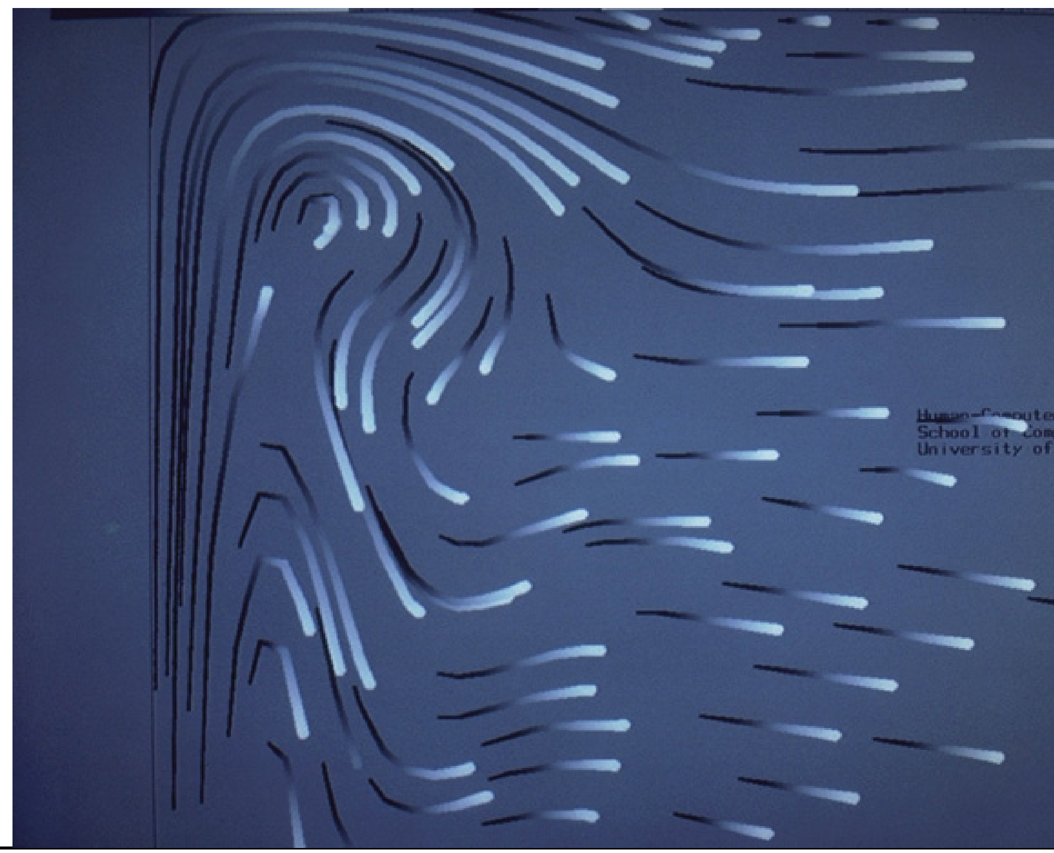
spiral sequence through color space

luminance increases with hue

from: Colin Ware

Color Perception - Conclusions

- Use luminance for detail, shape, and form
- Use color for coding - few colors
- Minimize contrast effects
- Strong colors for small areas - contrast in luminance with background
- Subtle colors can be used to segment large areas



luminance to signal direction

from: Colin Ware