Visualization – Perception

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Human Visual System

- Very fast processing of large amounts of data
- Sensory channel with highest bandwidth → channel with which information can best be transmitted error-free
- Permits perception of
  - Color
  - Texture
  - Movements
  - Objects, and
  - Relations between objects and groups of objects

Memory

- Different meanings when used in different contexts
  - Computers: part of hardware dedicated to storing data, can be accessed upon request
  - Organisms: function of the brain to:
    - store information
    - process and reason
    - constitute common ground for perception, categorization, interpretation, thinking
  - Brain stores memories based on perceived images
  - Cognitive psychology identifies several types of memories
    - Aim: understand how image is perceived and stored in memory
    - Types of memory have different durations of memory retention

Sensory memory *(iconic memory)*

- Ability of brain to retain impressions of signals coming from sensor organs for a very short period of time
- Able to automatically store visual information from eyes, independent of conscious control
  - *Preattentive processing:* without need for focused attention
  - First stage of visual perception
  - Generally within 200-250 ms
  - Rapid parallel processing by low-level vision system
  - Extraction of limited set of visual attributes: orientation, color, texture, and movement
  - Information ”pops out”

Short–term memory

- Transfer of some information from sensory to short-term memory
- Remains from few seconds to a minute (without rehearsal)
- Properties:
  - Limited storage capacity,
  - Is conscious,
  - Involves attentive process of perception
- Capacity can be increased → organizing information in *chunks*
  - Example: memorize phone numbers → easier to remember as several chunks of two or three numbers instead sequence of digits
- Visually mapped data is usually retained in short-term memory

Long-term memory

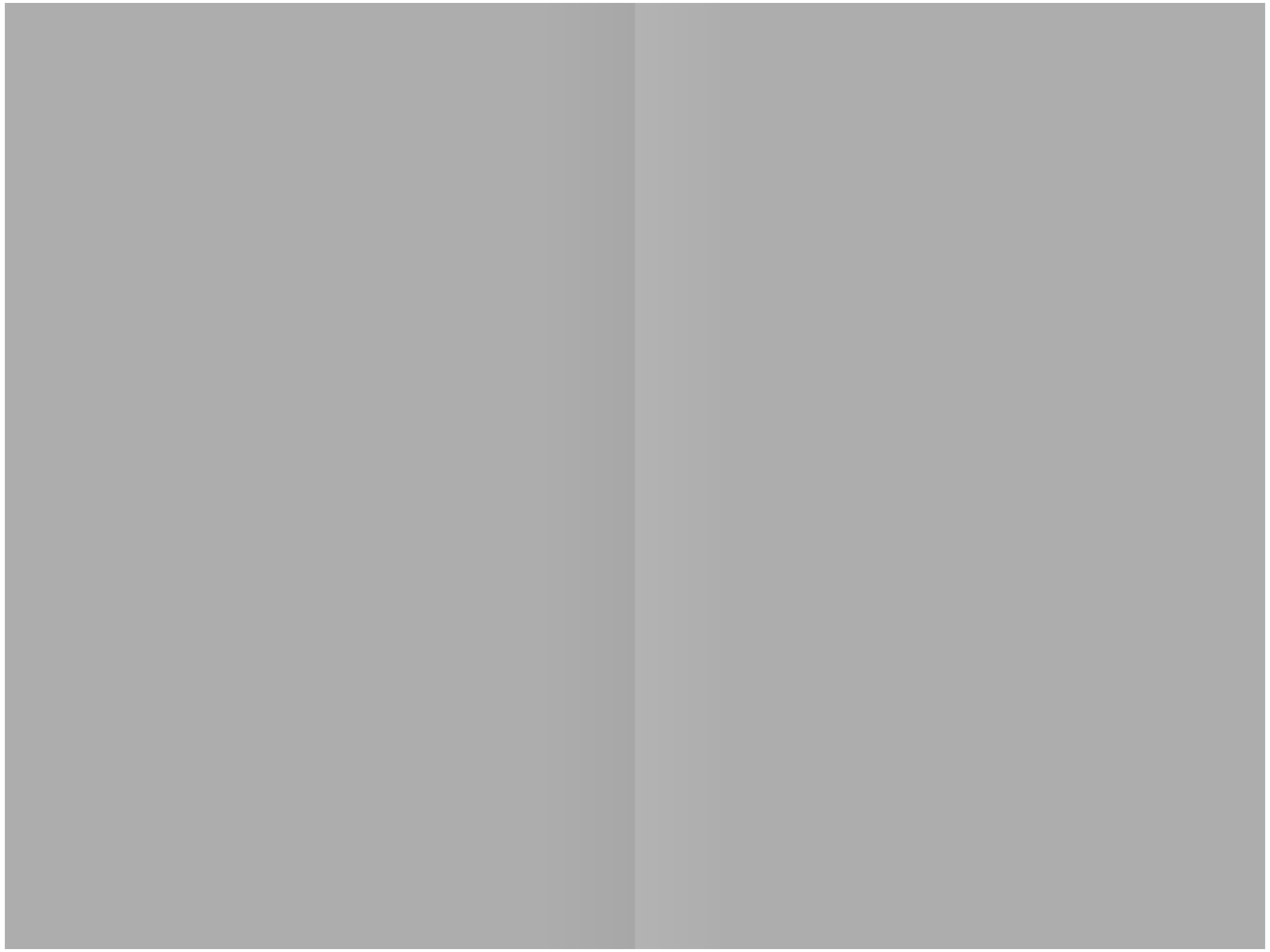
- Information in short-term memory is easily forgotten after a brief period of time
- Long-term memory stores information for many years, even for life
- Short-term memories became long-term by reinforcing the structure of neuronal synapses → *long-term potentiation*

Information Processing

Craik O‘Brien Cornsweet Illusion

Human eye amplifies edges

- Example: very faint gradient



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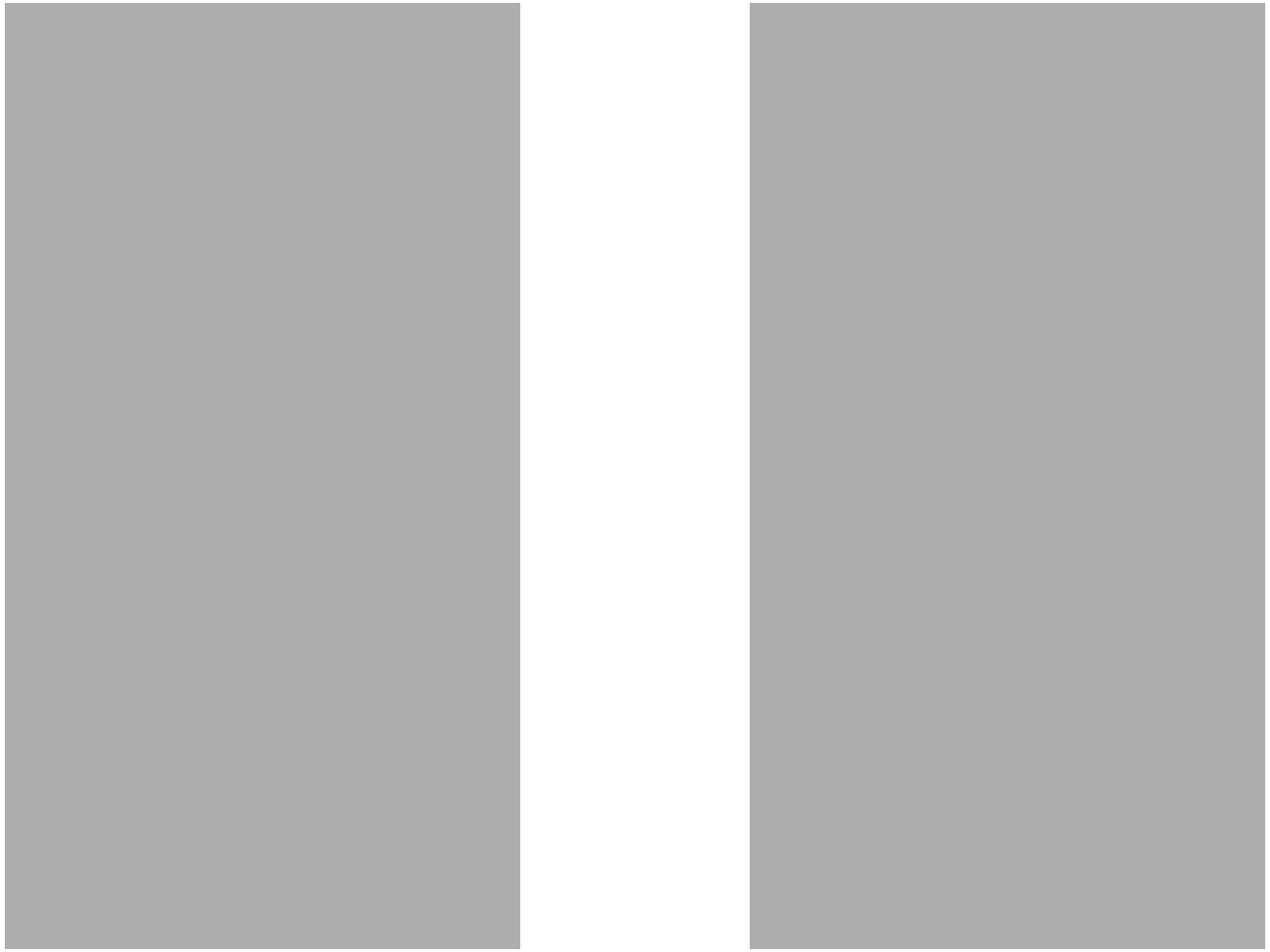
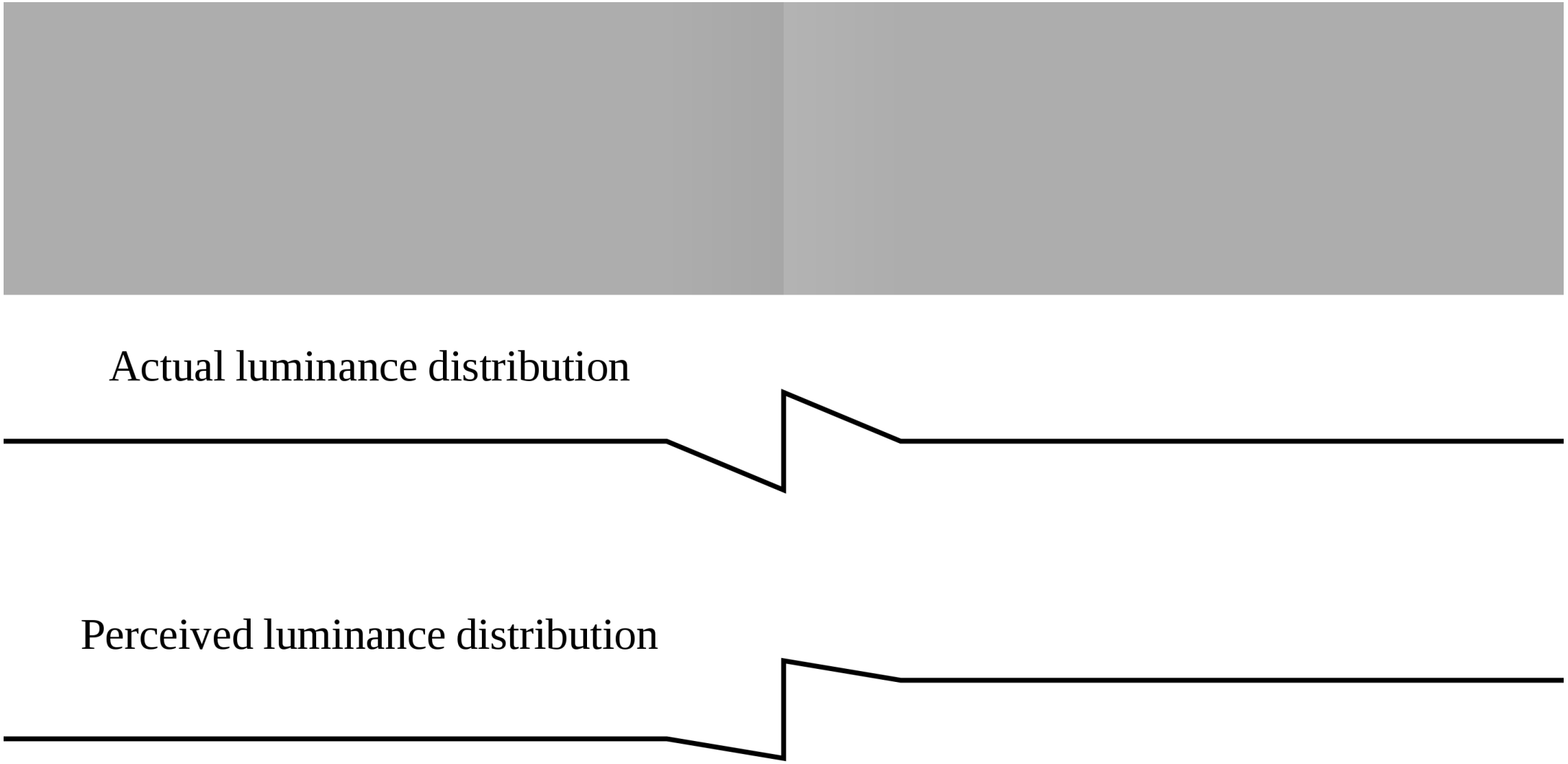
- Example: very faint gradient

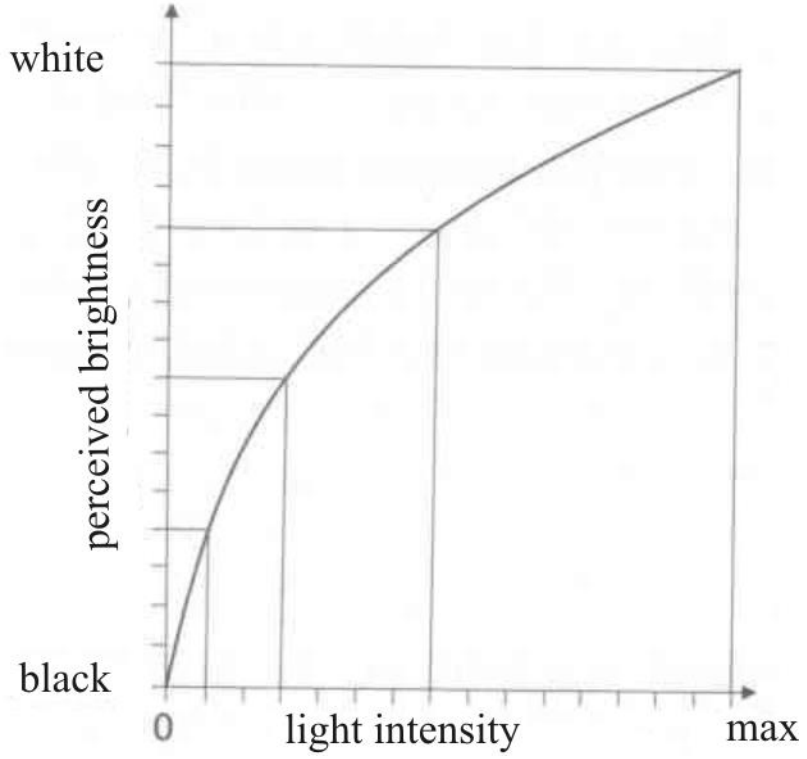


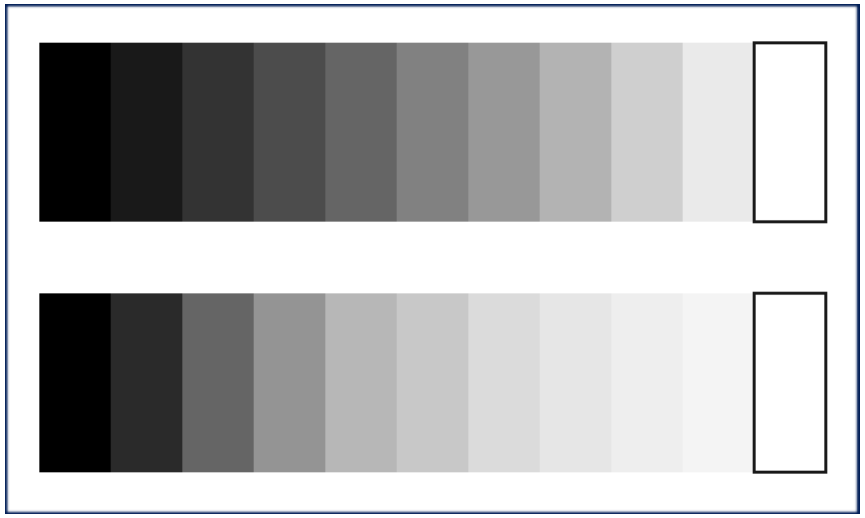
Craik O‘Brien Cornsweet Illusion



Luminance Perception

Non-linear relation between light intensity and perceived brightness

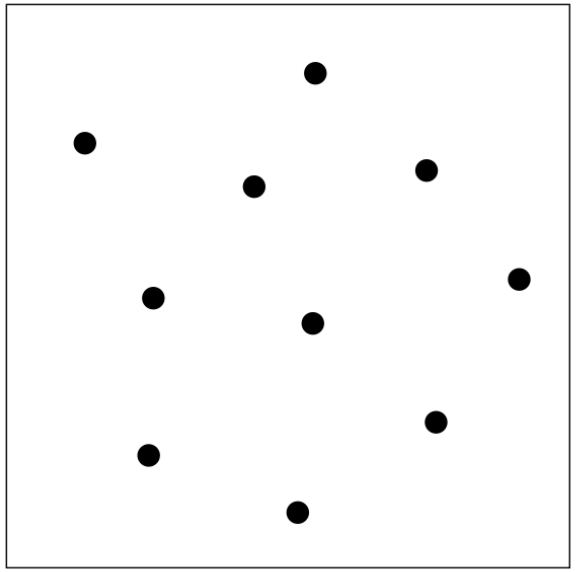




Above: linear perceived brightness
Below: linear light intensity

Weber–Fechner Law

- Psychophysical relationship in sensory physiology
- Linear increase in the (psychically) subjectively perceived strength of sensory impressions corresponds to the logarithm of the increase in the (physically) objectively measurable intensity of the stimulus



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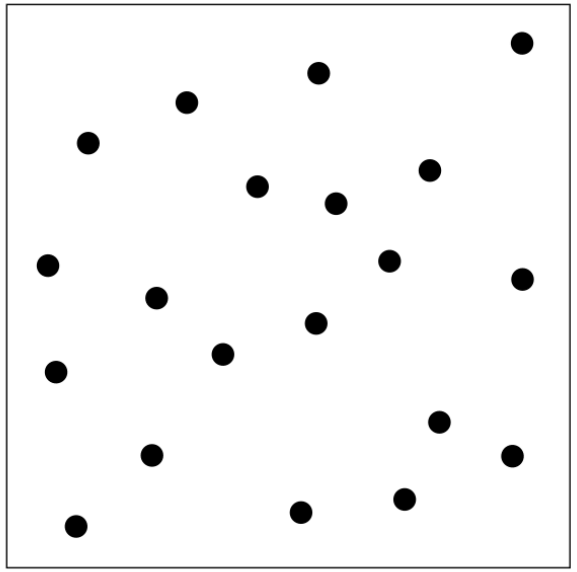

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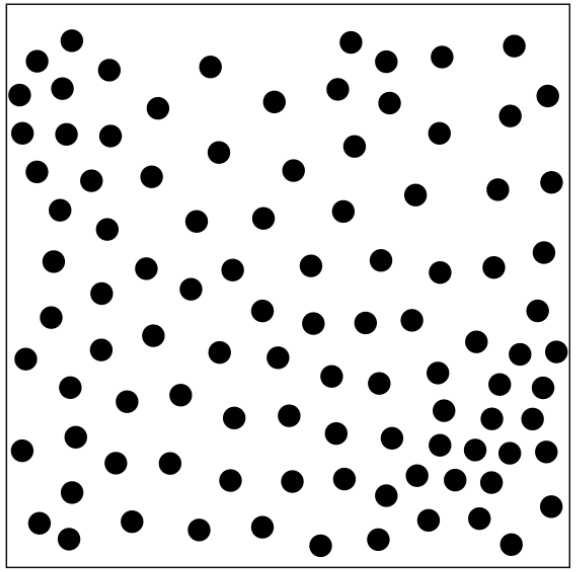

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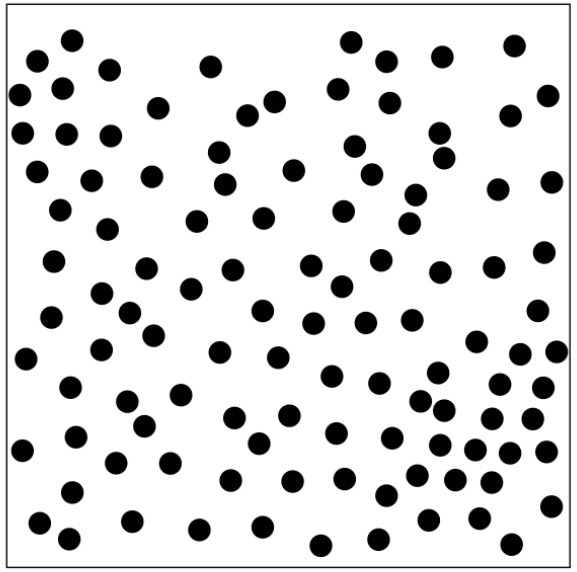


110

Luminance Perception

Consequences from Weber's law:

- For the visualization of quantitative data, grey values should not be assigned linearly to data values.
- Differences between adjacent grey values must be recognizable.
- To discriminate a grey value from black, ~15% white should be used. Following differences are smaller.

Grey value maps

- ... are used a lot in practice, e.g., medical imaging
- ... interfere with surface shading (don't use in 3D)
- ... heavily depend on background (easily 20% error) [Ware 98]

Luminance Perception

Dependence on the background

[Moreland 2009]

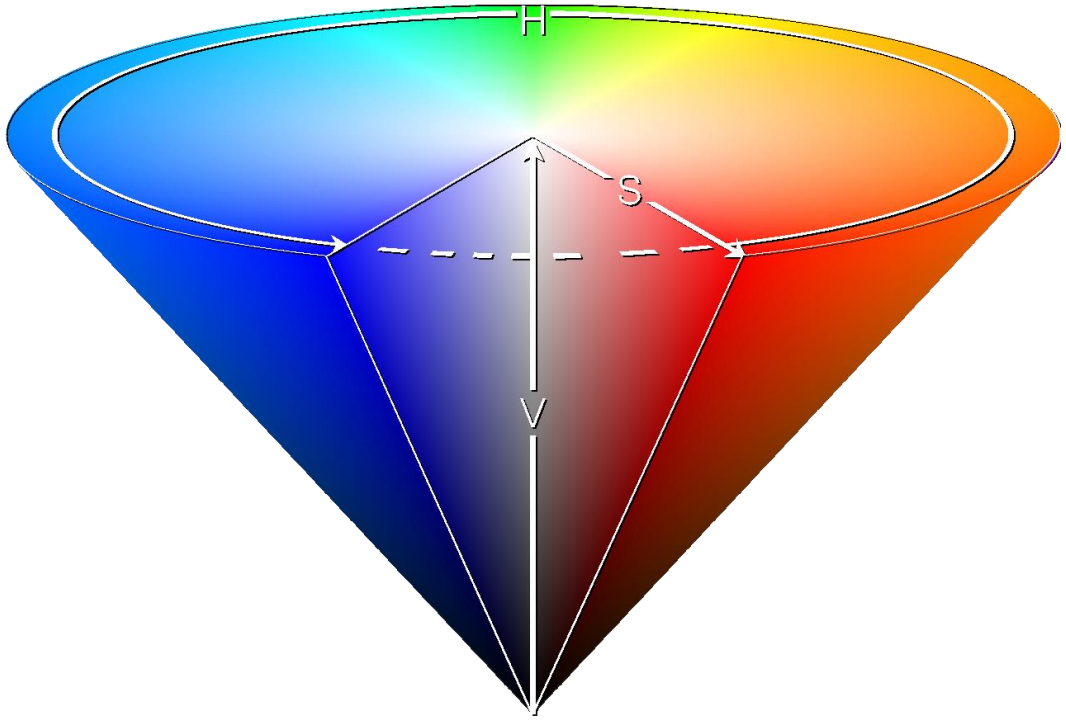
Luminance Perception

Dependence on the background

The perceived brightness depends on the background.

[Moreland 2009]

Color Perception



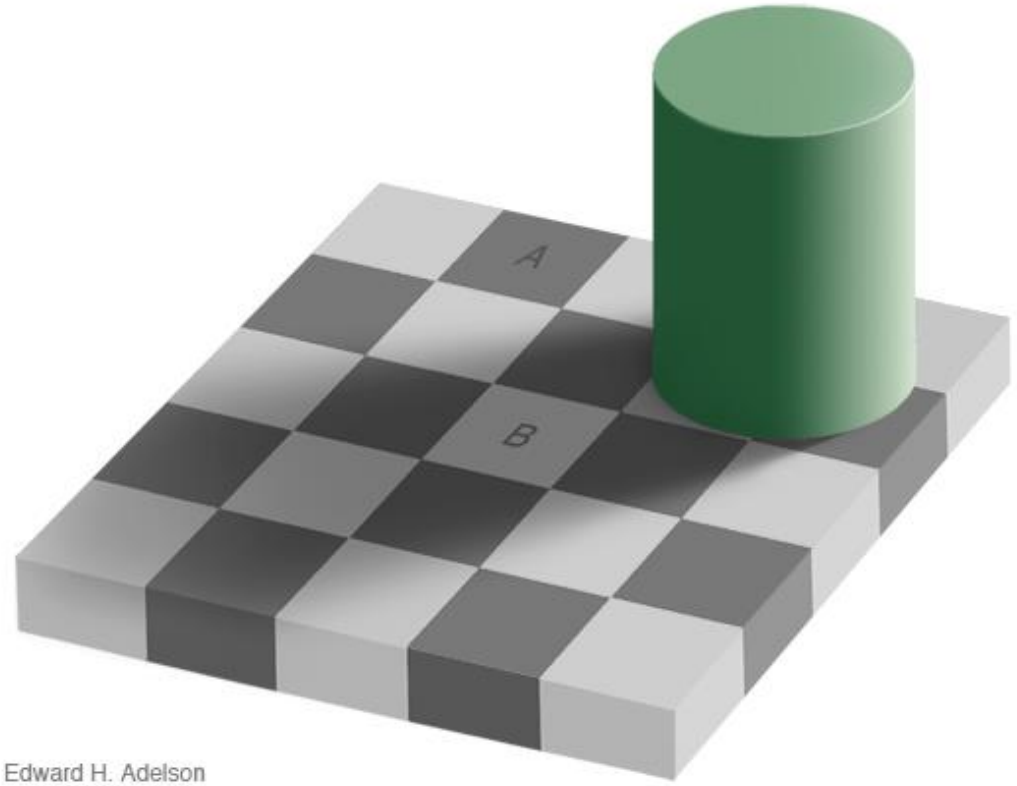
Color space: HSV-Model

- HSV: Hue, Saturation, Value
- appropriate for the interpolation of colors

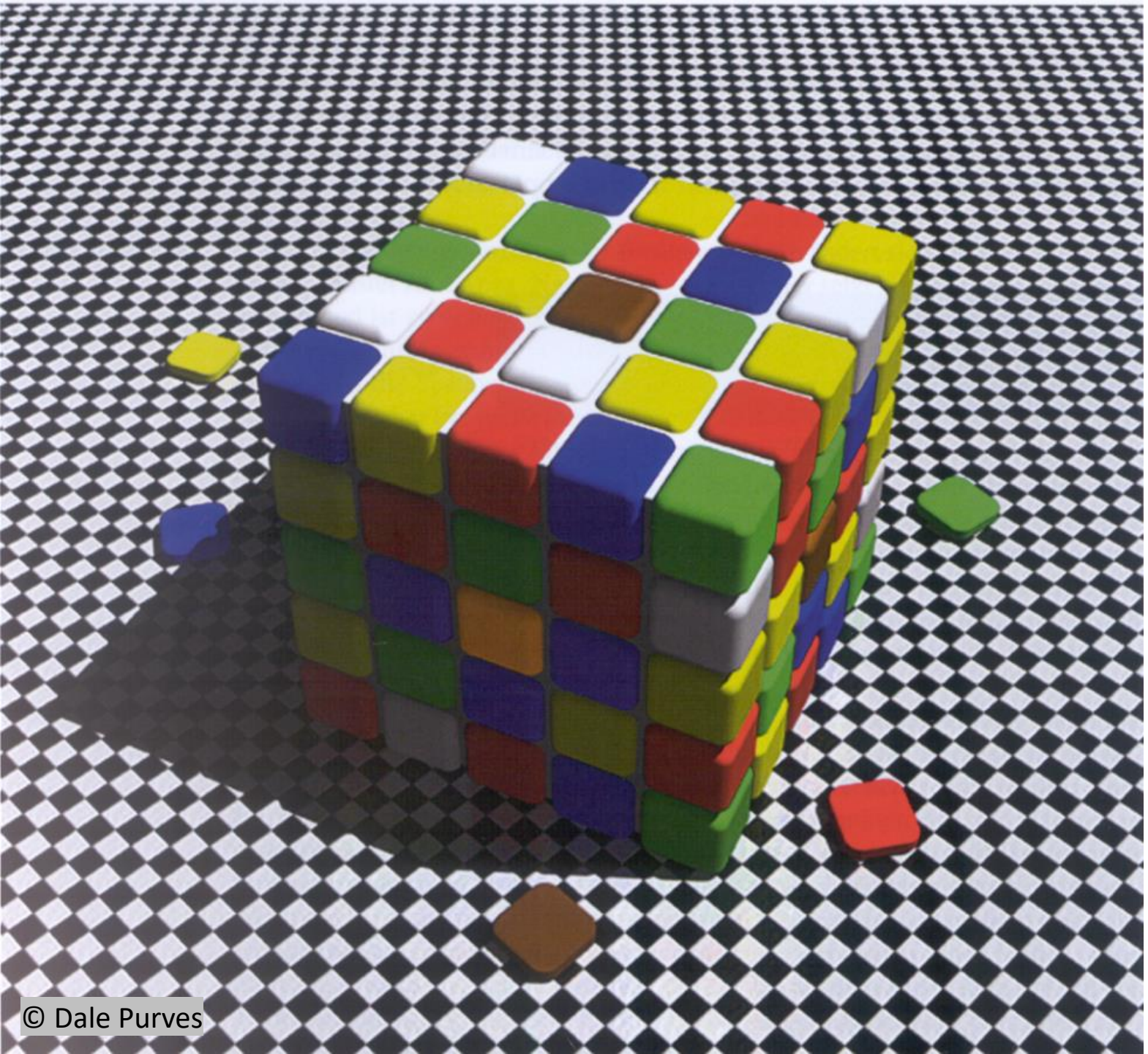
- Rule of thumb:
  - Distinguish about 200 colors (H)
  - Varying the intensity perceive about 500 gradations (S)
  - Another 20 variations per color tone (V)
  - Perception up to about 20 million colors

Color Appearance: Color Constancy

- How color appears to us depends on a lot of factors.
- For example, color is influenced by shadows.

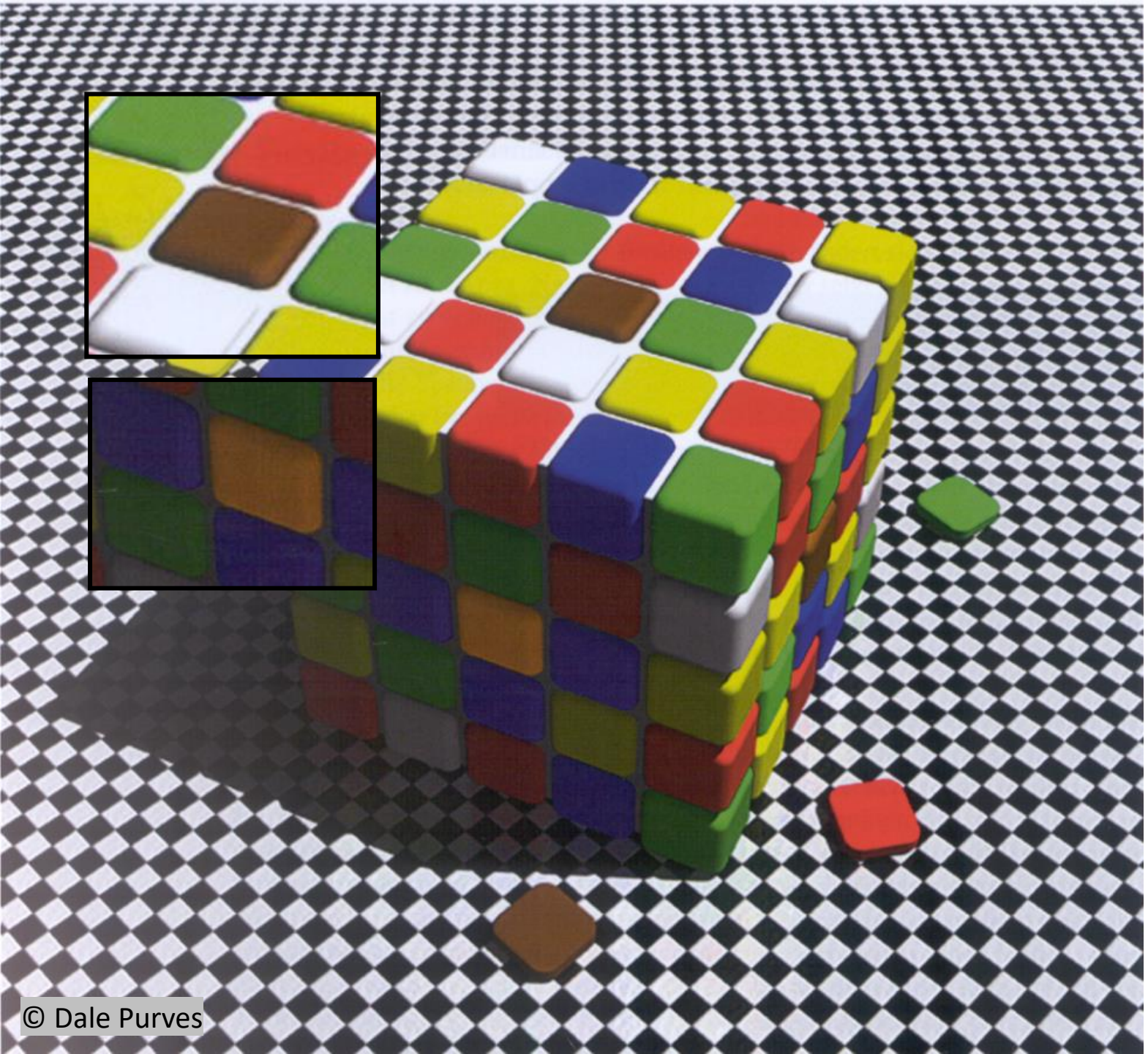


http://twistedsifter.com/2012/05/optical-illusions-made-from-shadows/



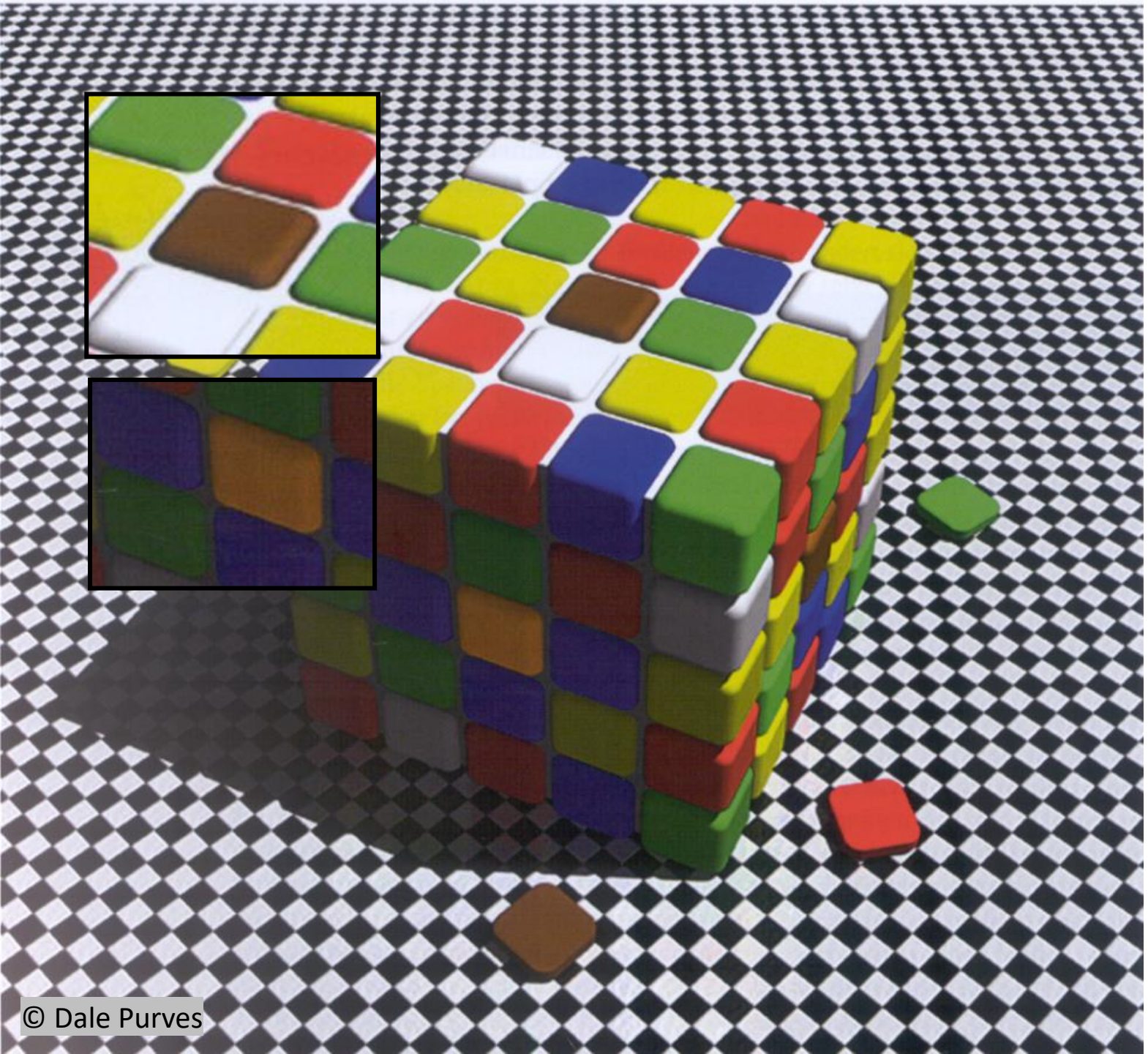
Color Perception

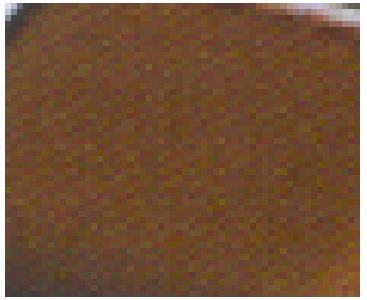
- Color constancy

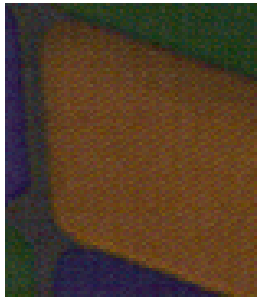


Color Perception

- Color constancy
- Brown (on top) and orange (in the shadow) are clearly distinguished



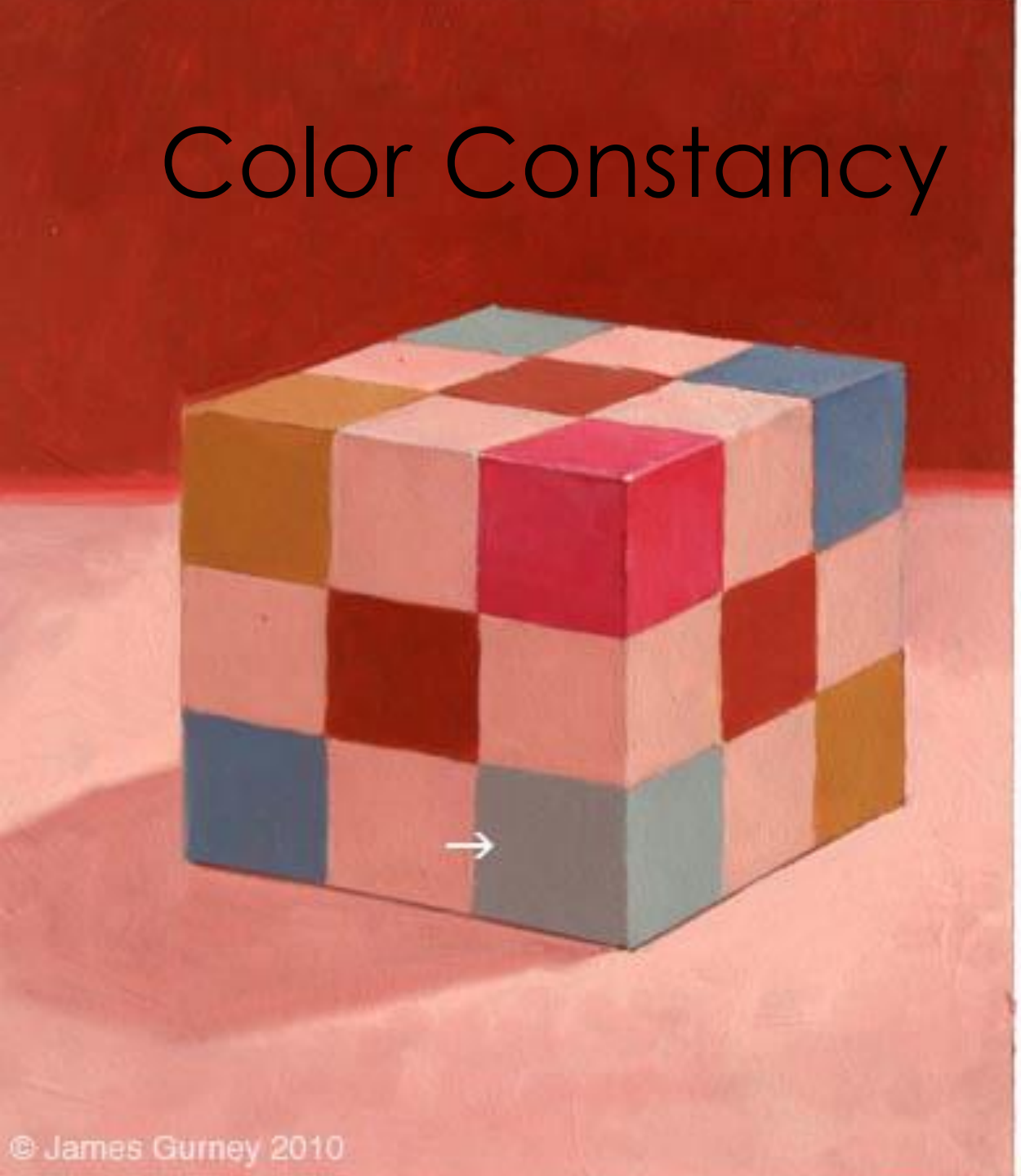




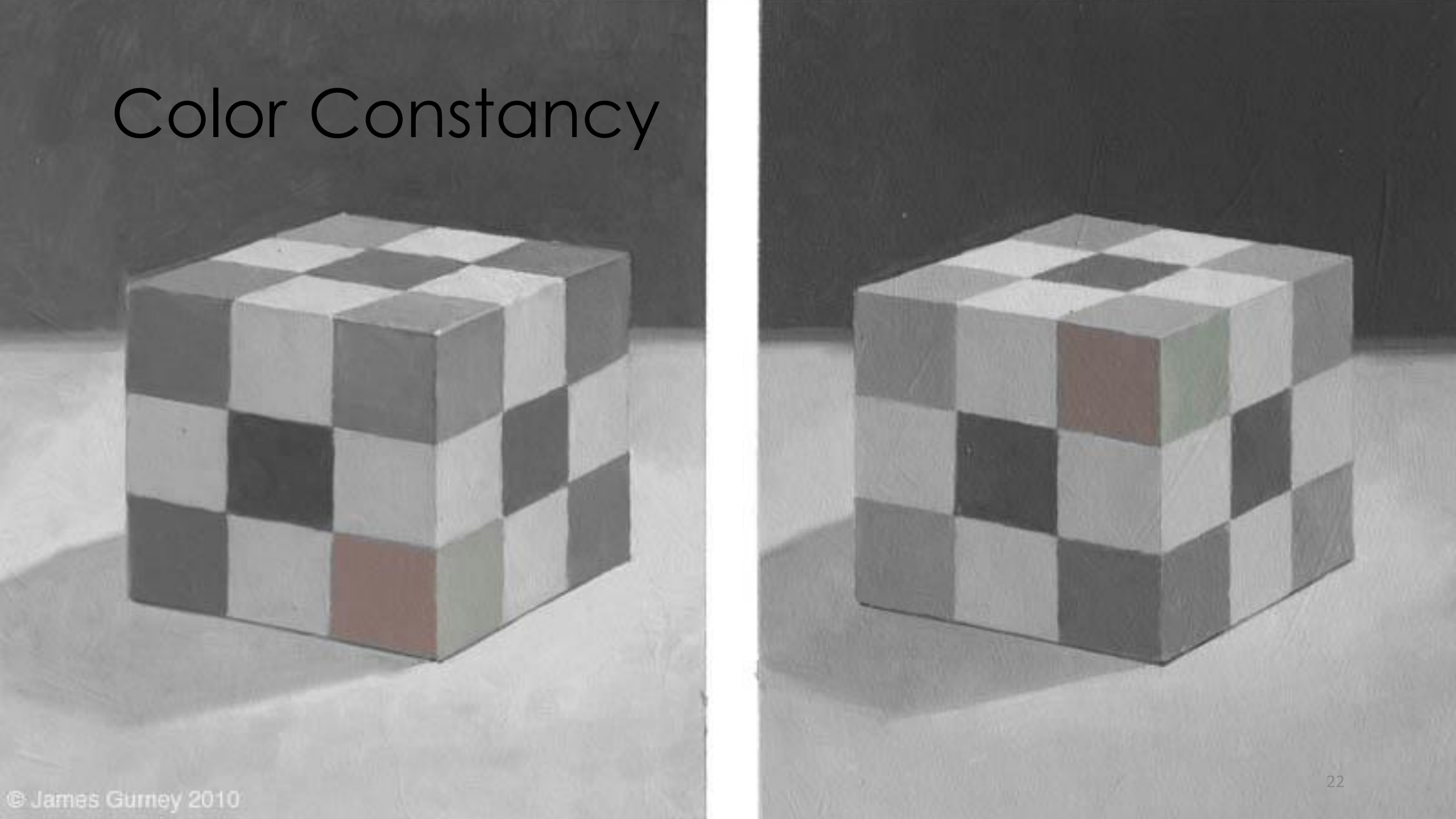
Color Perception

- Color constancy
- Brown (on top) and orange (in the shadow) are clearly distinguished
- The actual light intensity and wavelength are the same

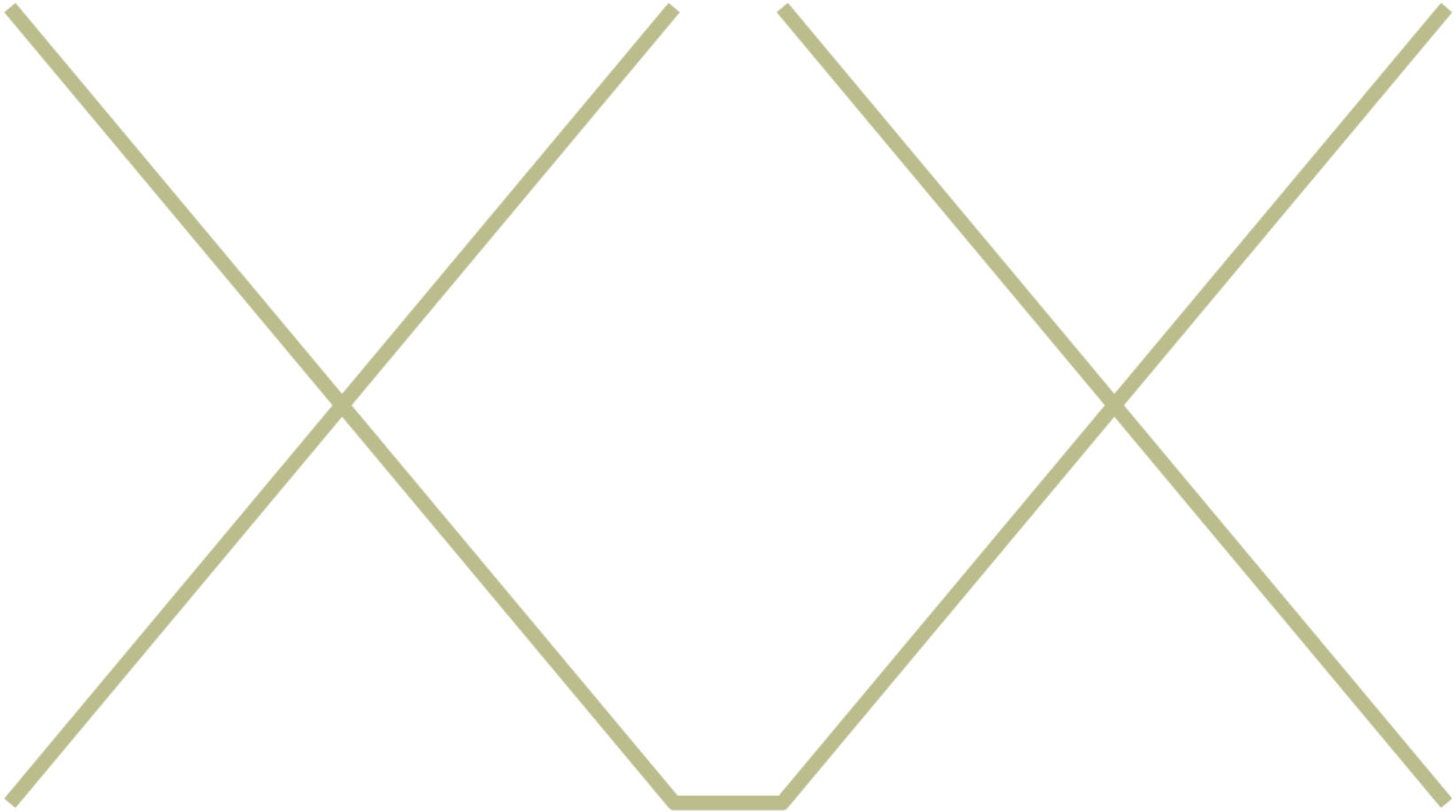
Color Constancy



Color Constancy

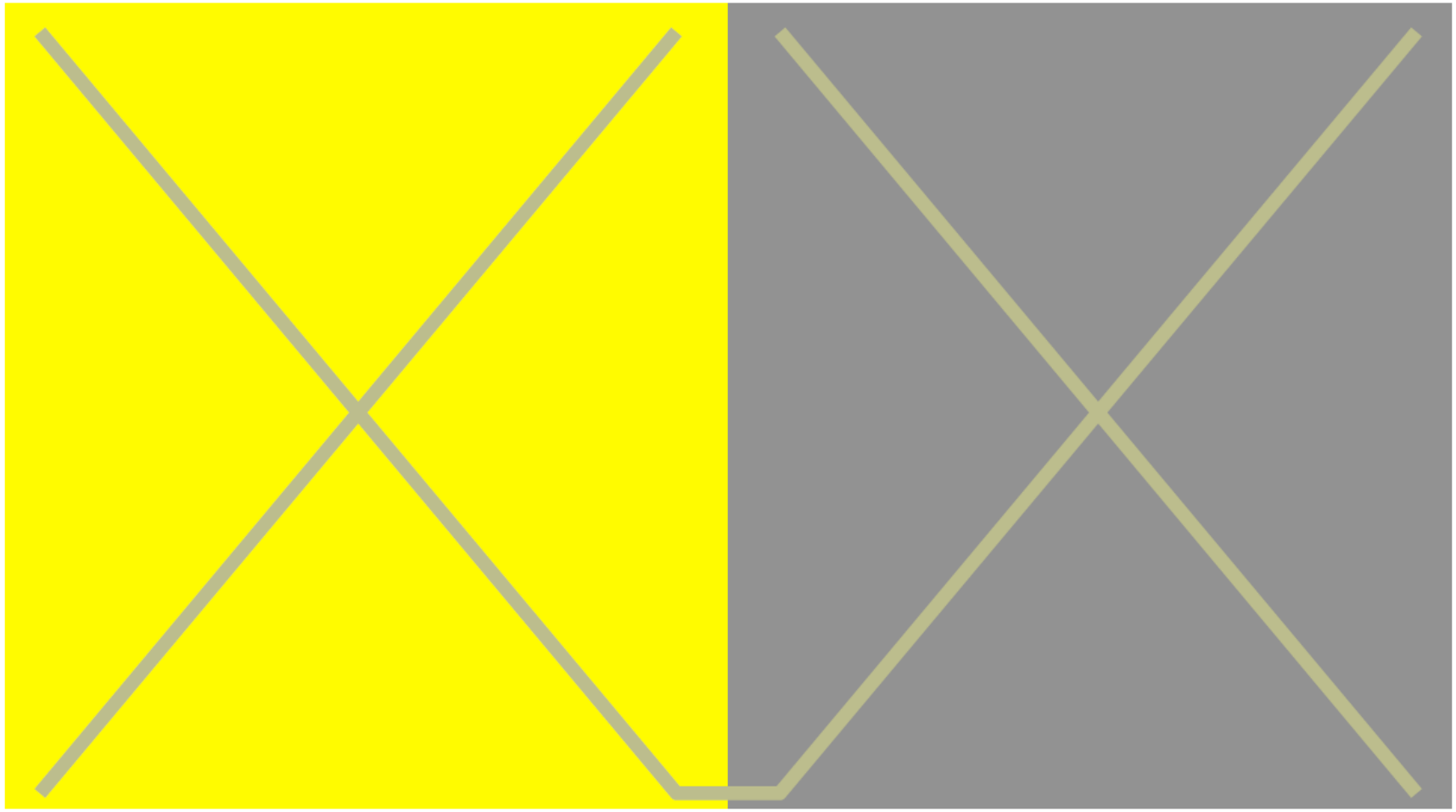


Color Appearance: Simultaneous Contrast



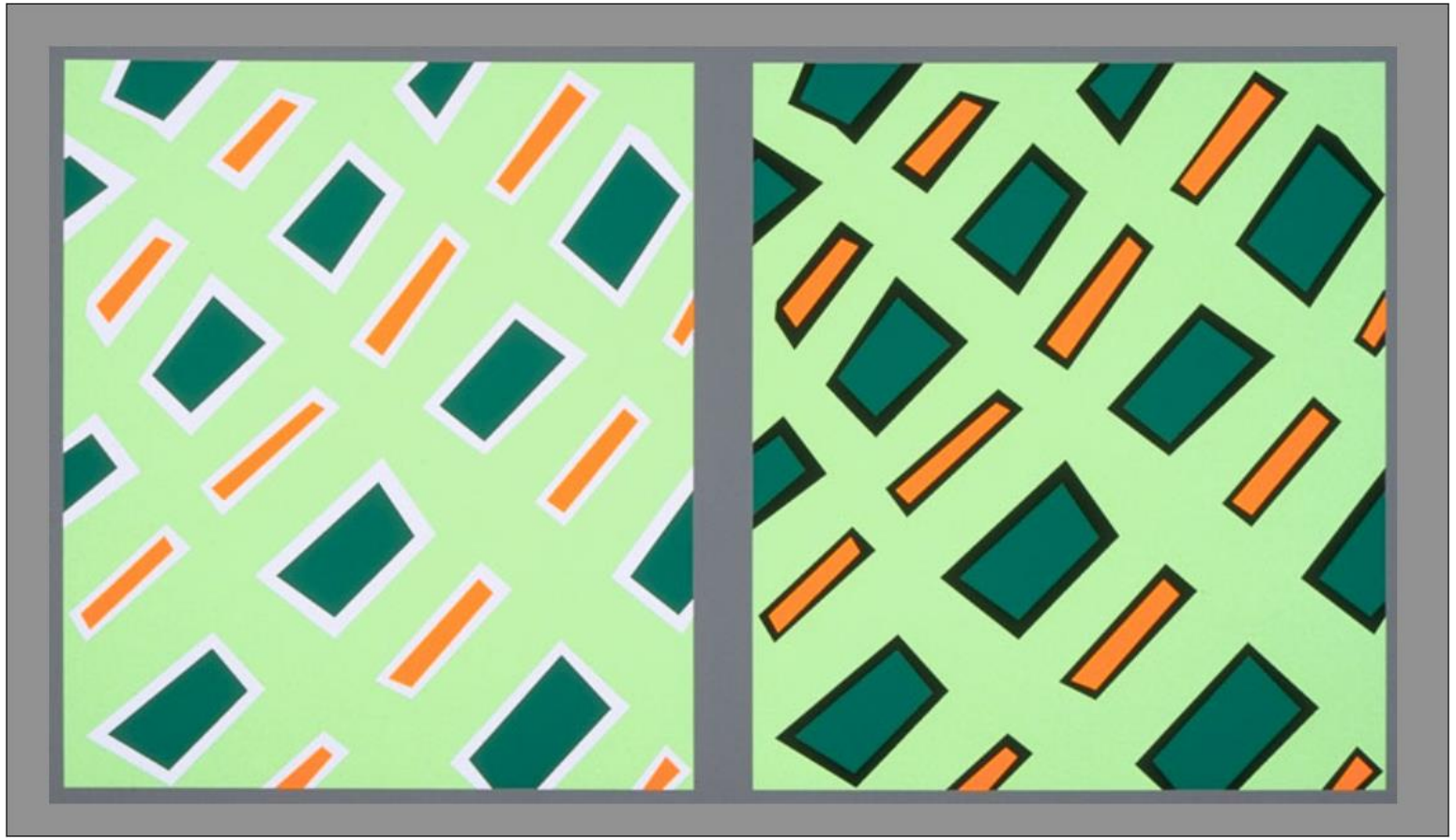
Color Appearance: Simultaneous Contrast

Color is influenced by adjacent colors.



Color Appearance: Bezold Effect

Changing a single color leads to a shift of all colors.



Color Appearance: Crispening

Perceived color difference depends on the background.

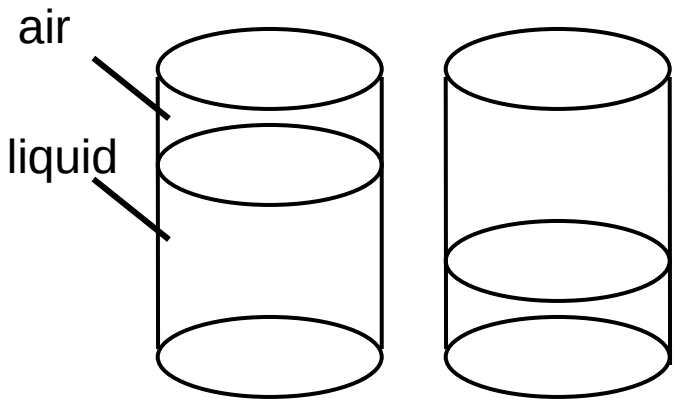
[Fairchild04]

Color Appearance: Spreading

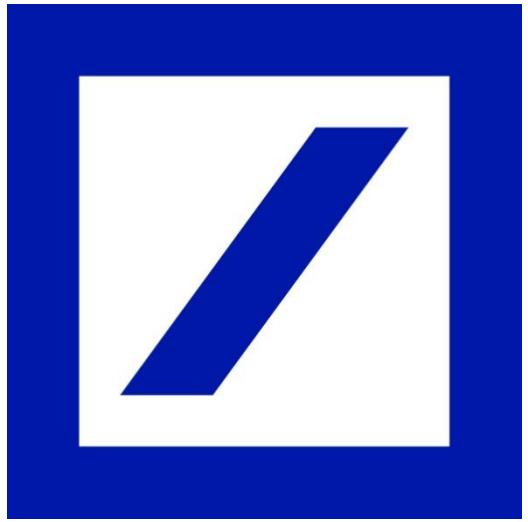
Colors mix with increasing spatial frequency

[Fairchild04]

Image Interpretation: The Role of Experience



A normal glas and a glas on top?



A decreasing or an increasing line?

Image Interpretation: The Role of Experience

Letters are interrupted. Which portion of shapes belong together?

Stripes indicate occlusion and the underlying objects are perceived as continuous but hidden.

Image Interpretation: The Role of Experience

- What do we have here?

Image Interpretation: Spatial Relations

Support for correct spatial perception of images:

- Consider expectations
- Integrate depth-cues
  - Shadow projection
  - Illumination effects
  - Stereo rendering
  - Perspective
  - Attenuation of distant portions (depth of field blur)
  - Occlusions should be obvious

Image Interpretation: Spatial Relations

Shadow projection on a plane enhances spatial perception.

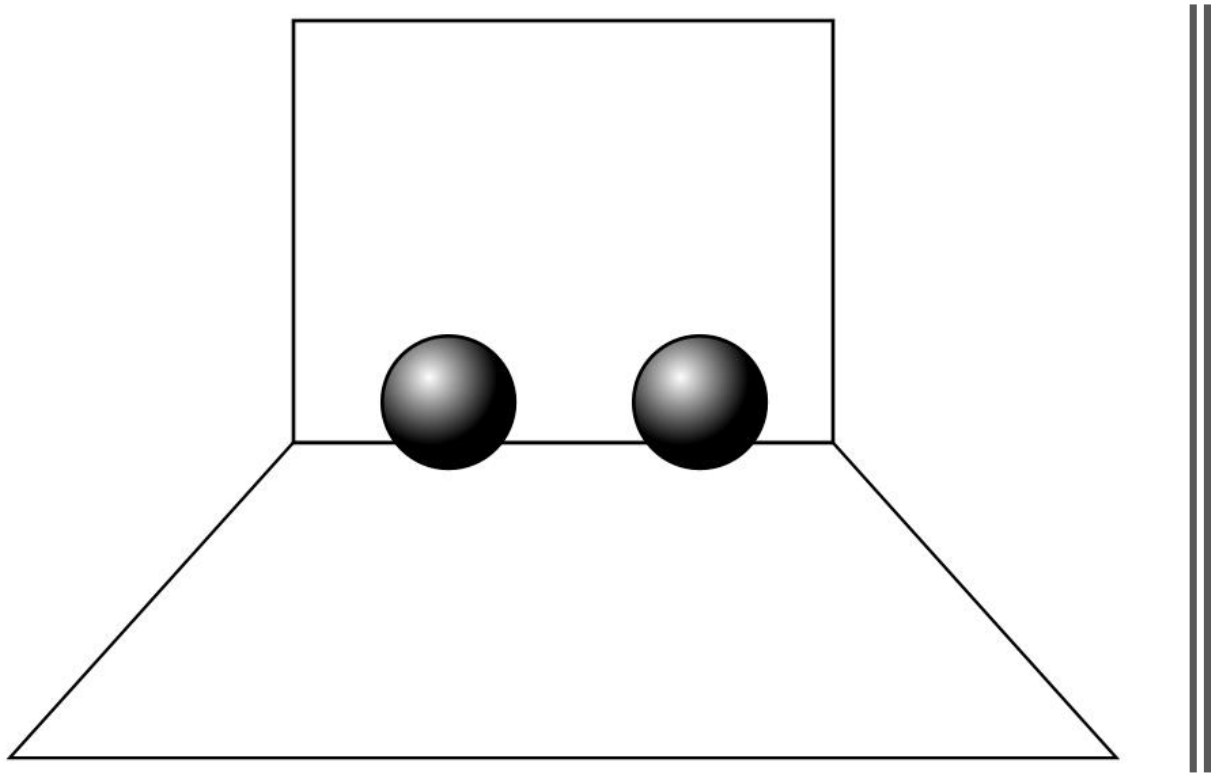
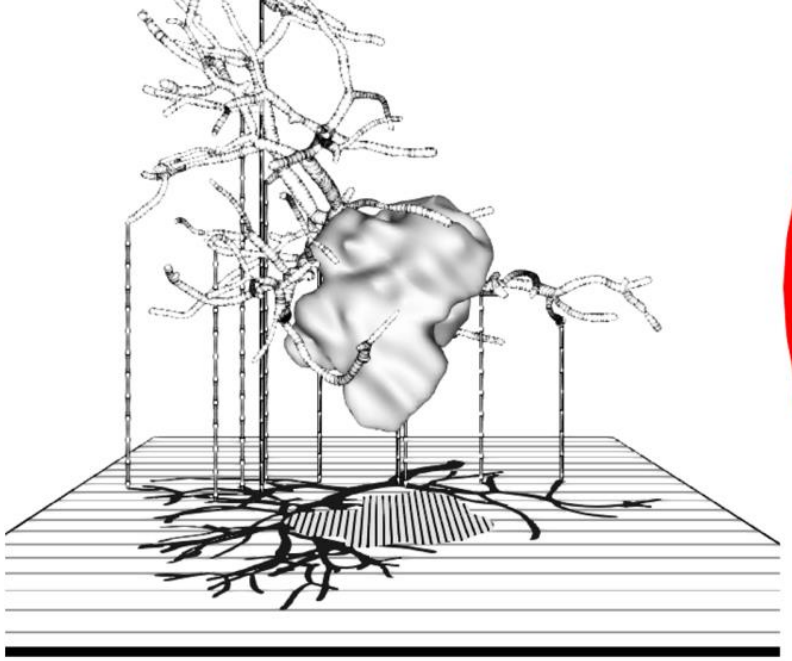
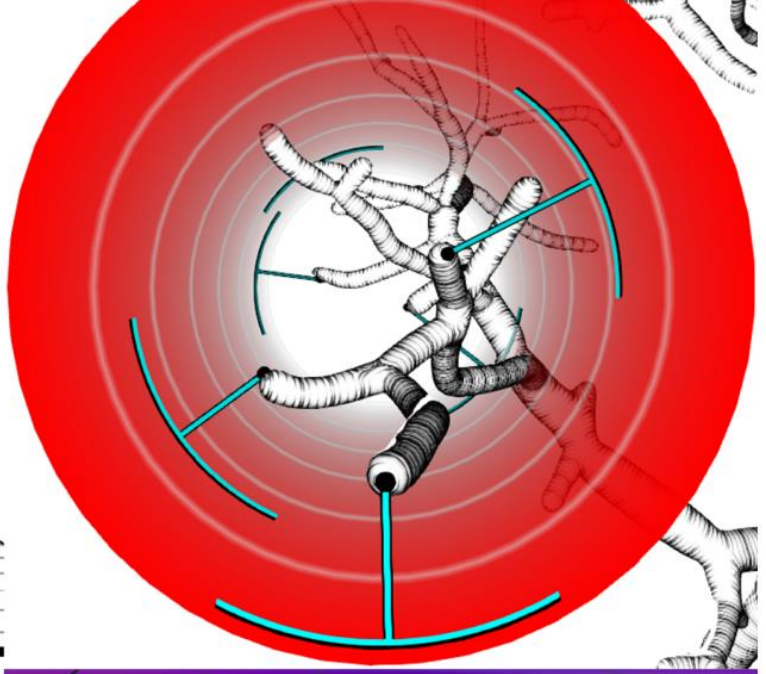
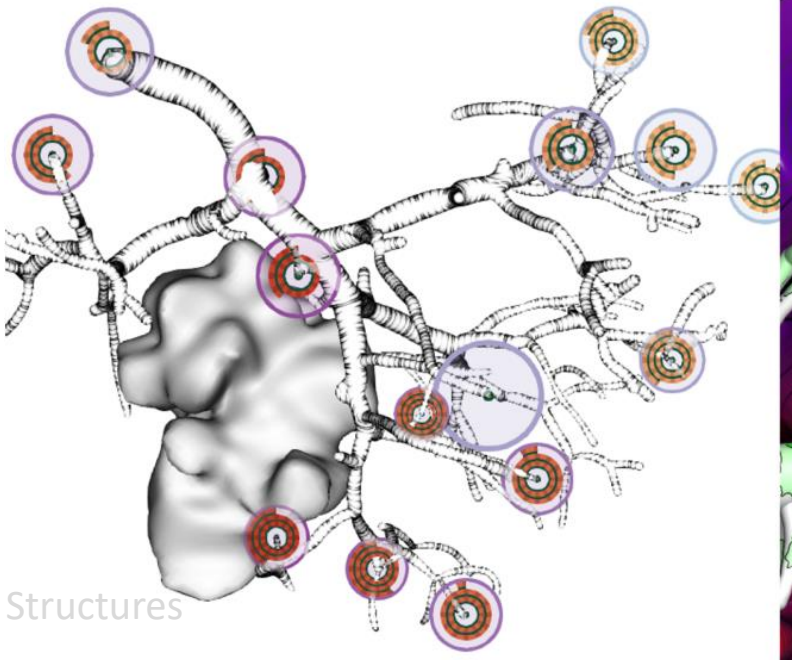


Image Interpretation: Spatial Relations

Beyond shadows







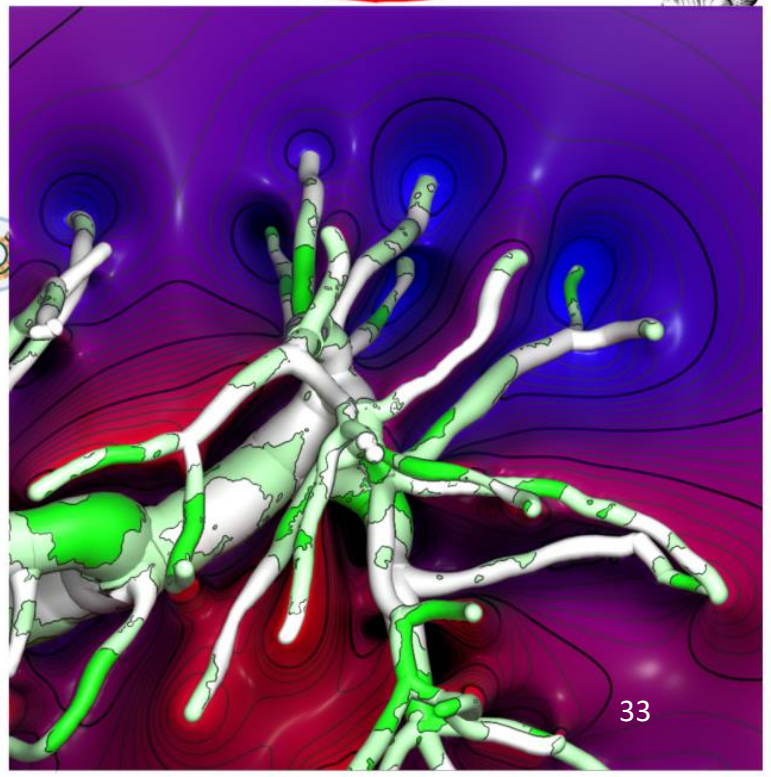


Image Interpretation: Spatial Relations

Shape recognition is enhanced by lateral light compared to frontal light.

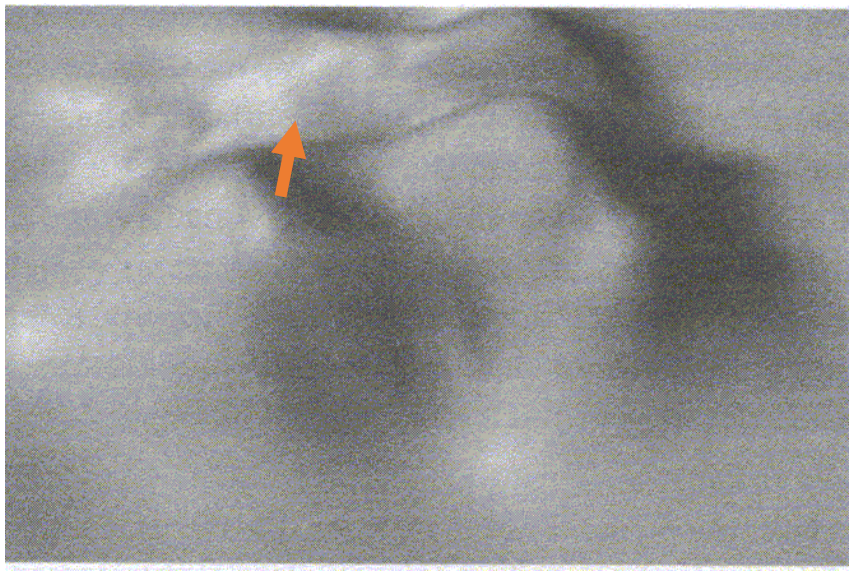
Hard shadows are disturbing.

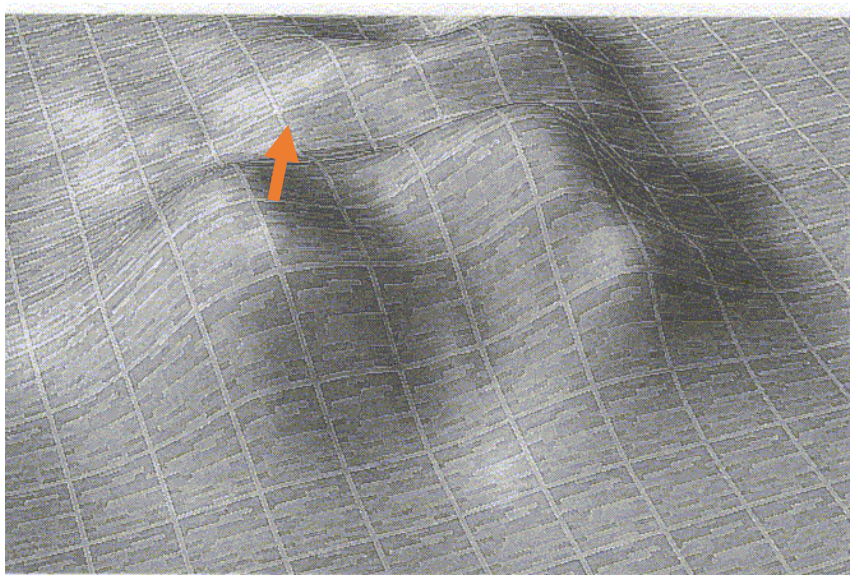
[Brugger 1995]

Image Interpretation: Spatial Relations

Textured surfaces are more correctly interpreted than (raw) surfaces

- Study design: users should estimate the surface orientation at selected positions.



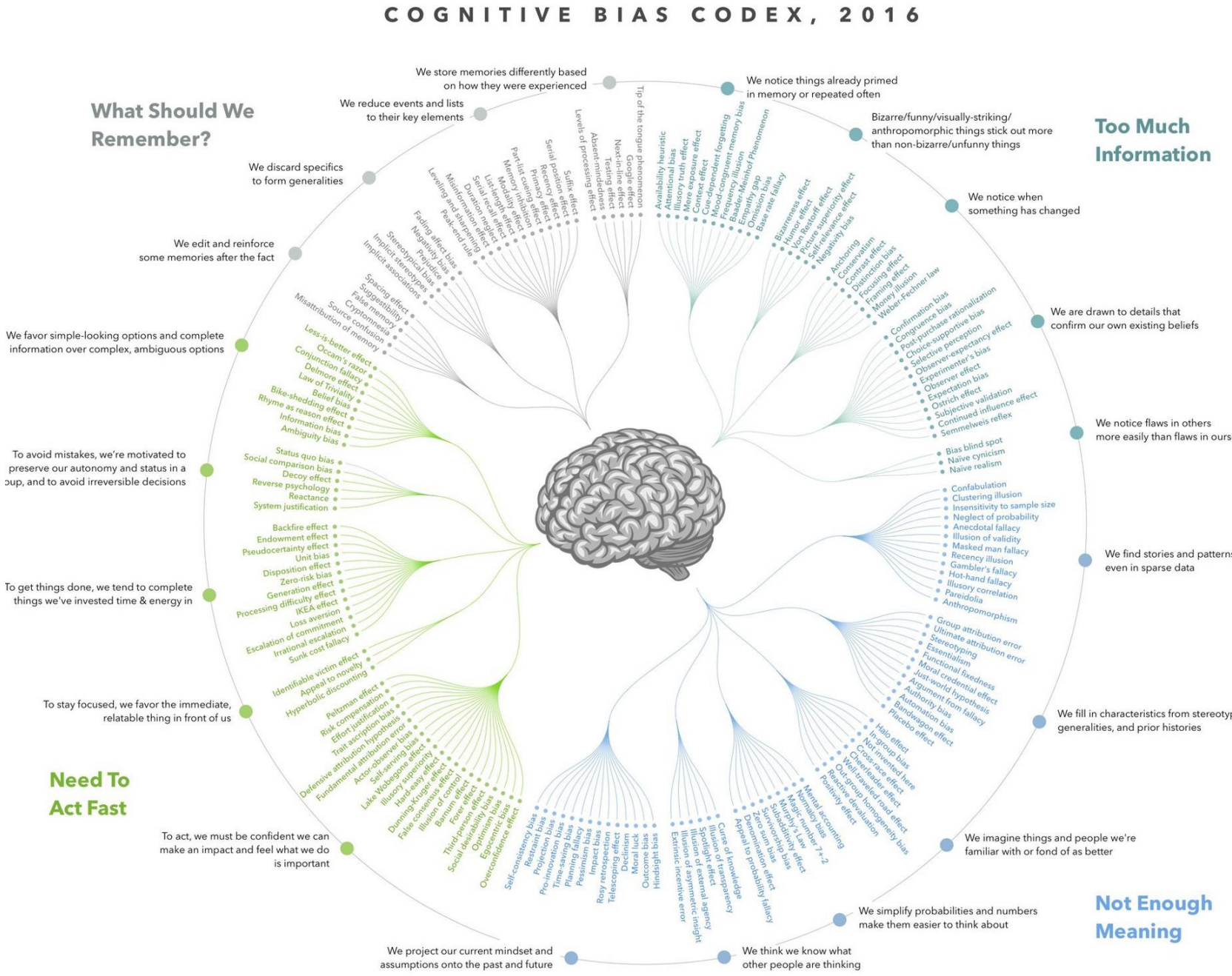


Ware 2001

Cognitive Biases

Humans make many mistakes…

- There are more than one hundred cognitive biases!
- How to design visualizations so that we make less mistakes?



John Manoogian III, https://betterhumans.coach.me/cognitive-bias-cheat-sheet-55a472476b18

Preattentive Perception vs. "Parsing"

Two Stages of Visual Perception

Stage 1: Parallel processing to extract low-level properties

- rapid parallel processing at the retina
- extraction of features, orientation, color, texture and movement
- transitory nature of information (held briefly)
- bottom-up processing without special attention

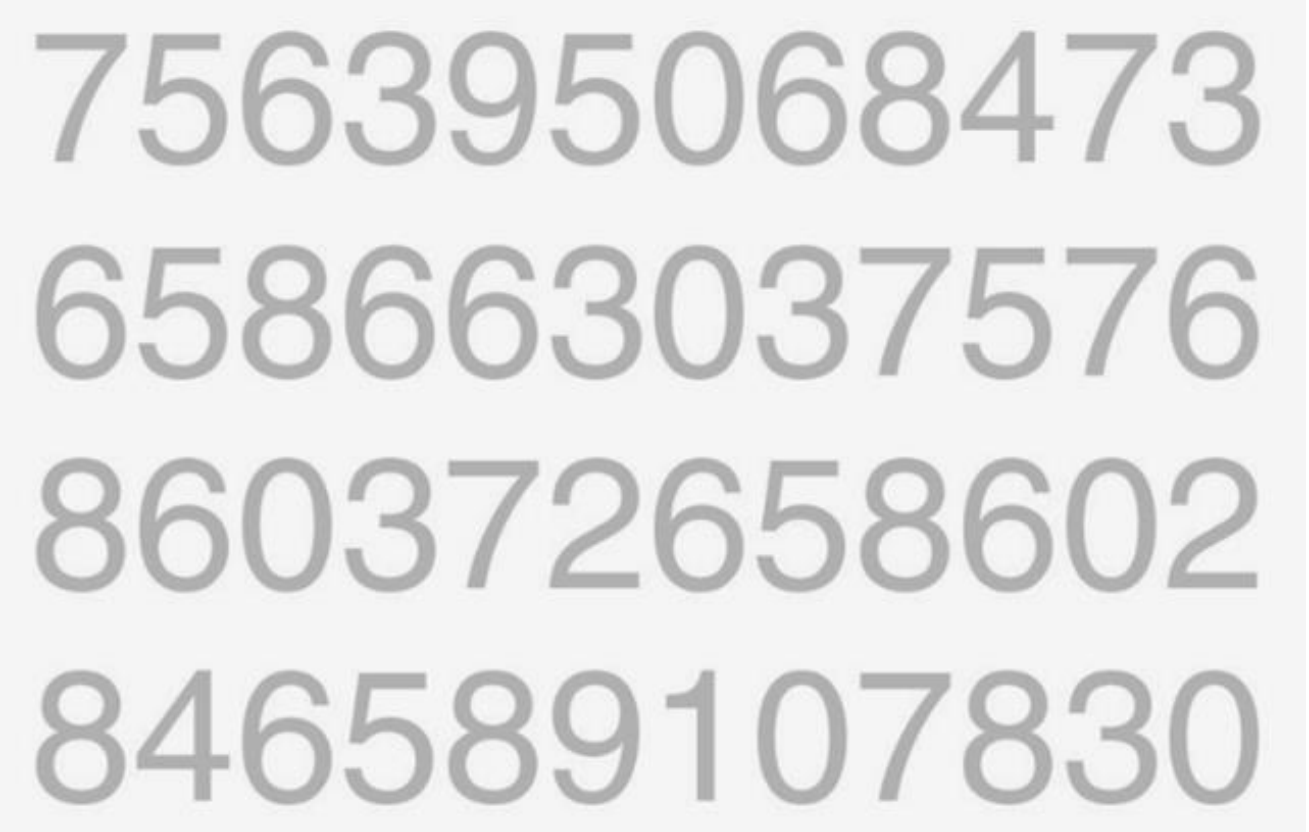
Stage 2: Sequential goal-directed processing

- slow serial processing
- involvement of short term and long term memory
- more emphasis on symbol recognition
- top-down processing (directed by goals)

If we know what is perceived in stage 1, we can encode important information such that it is perceived without cognitive effort.

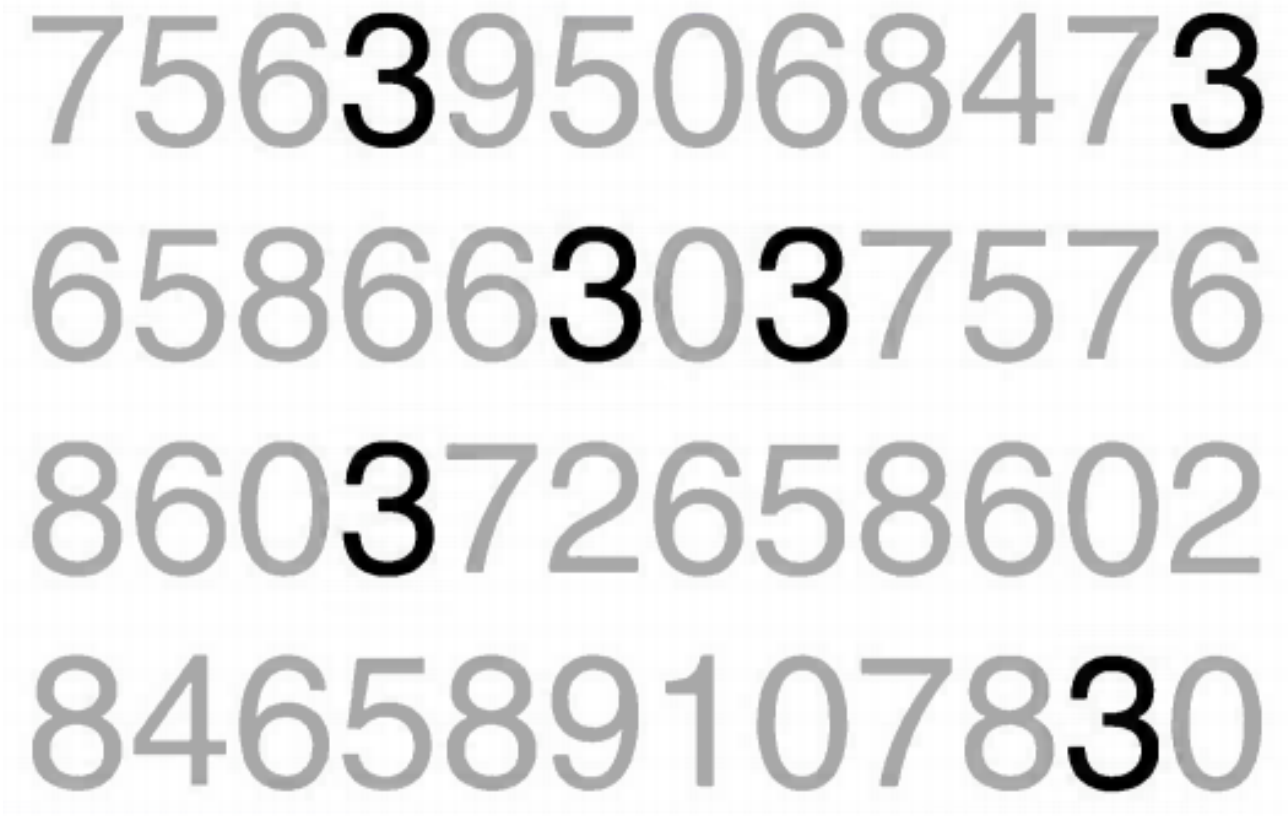
Stages of Visual Perception

Count the 3’s



Stages of Visual Perception

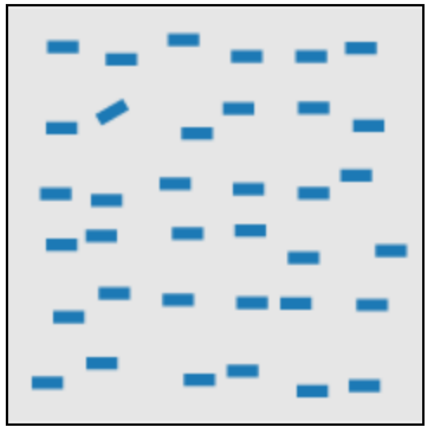
Count them again

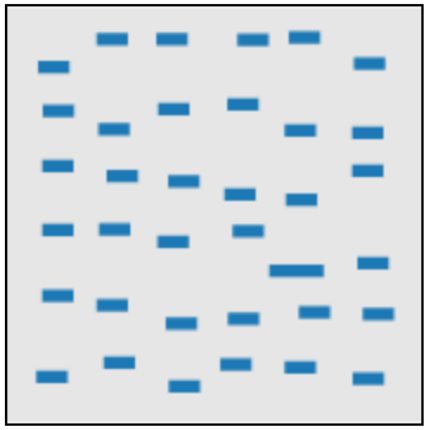


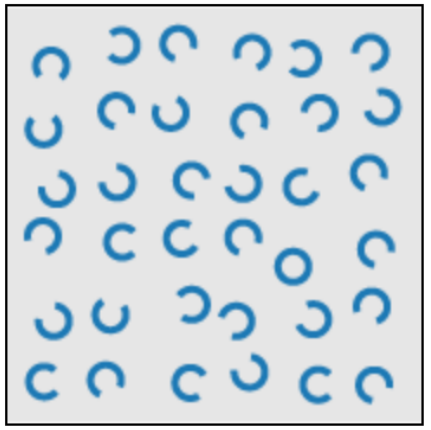
Why is it so easy to count the 3's now?

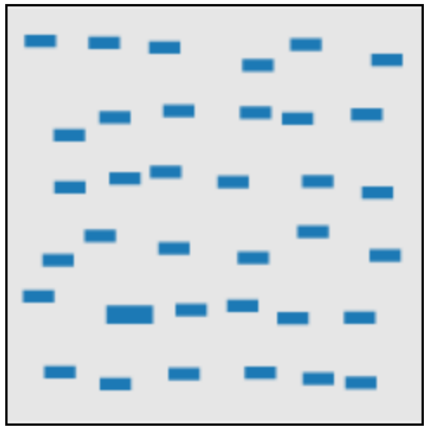
Stage I

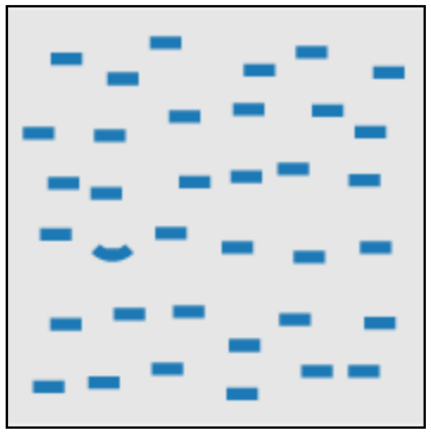
- Some…

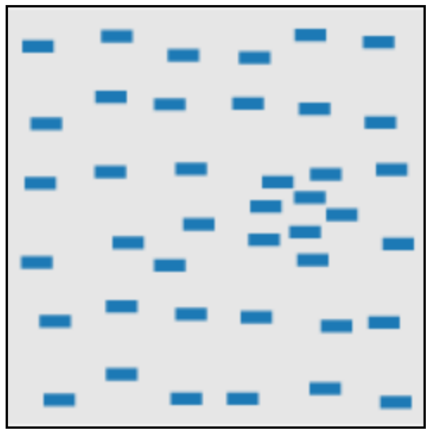

line (blob) orientation

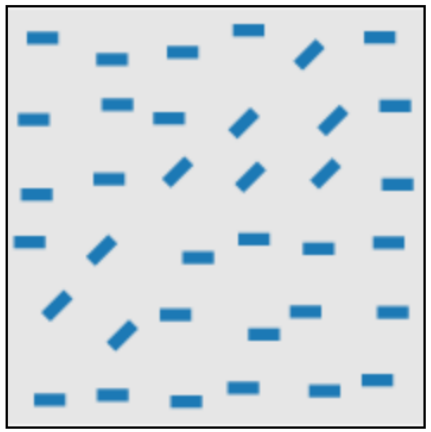

length, width

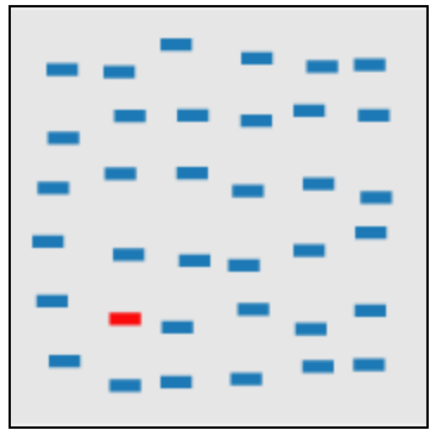

closure

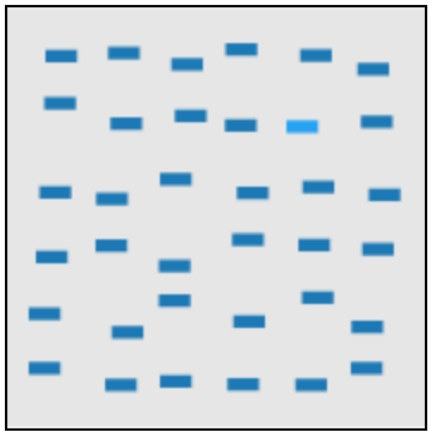

size

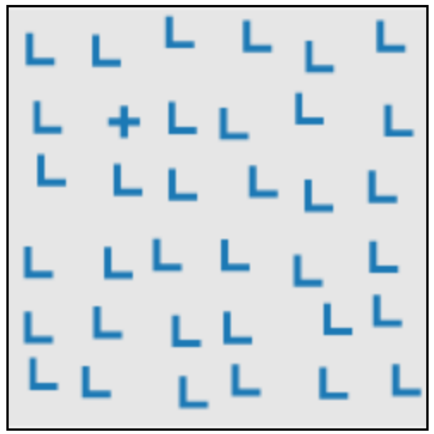

curvature

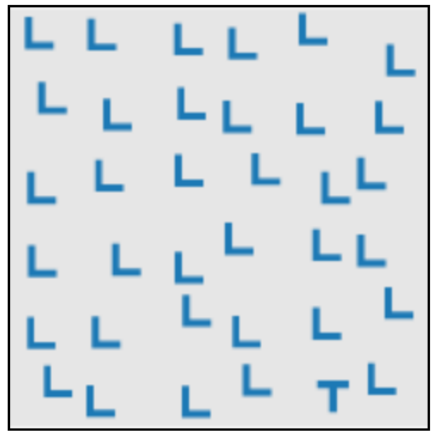

density, contrast

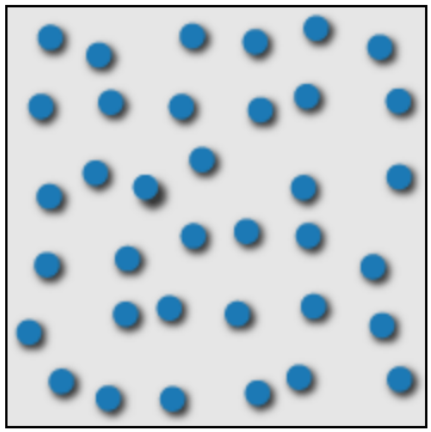

number, estimation


colour (hue)


intensity, binocular lustre


intersection


terminators


3D depth cues

https://www.csc2.ncsu.edu/faculty/healey/PP/

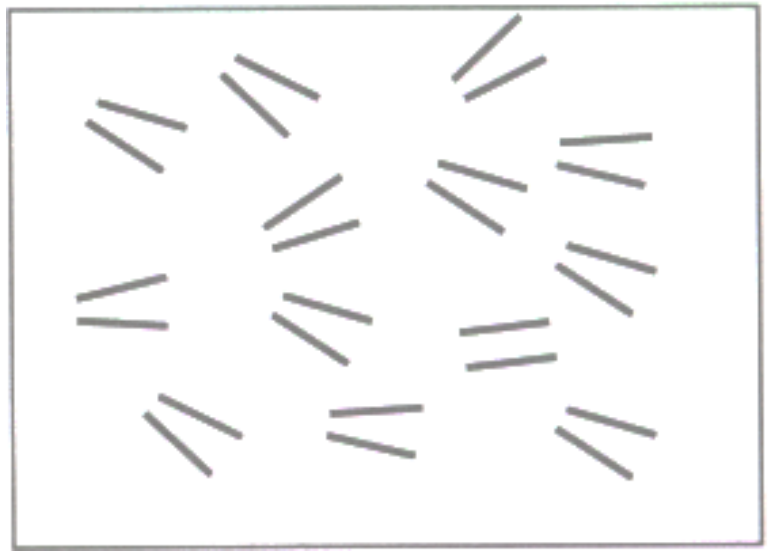
Preattentive Visual Features

- Very powerful, as they are immediately perceived
- Number of preattentive attributes that can be used in a single representation, and number of visual distinctions of a single attribute, are limited are due to short-term memory
- Ware et al. [Ware01]:
  - no more than eight different hues
  - four different orientations
  - four different sizes
  - all other visual preattentive attributes to less than 10 distinct values
- Few et al. [Few04]: limiting number of distinctions, for any attribute, to no more than four

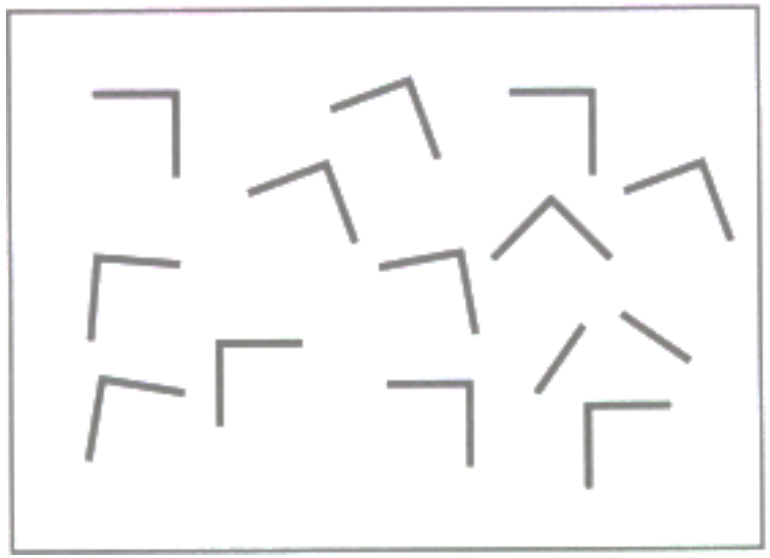
Examples for Non-Preattentive Features

- Perception of these differences requires attention (second stage of visual perception)
- Slow serial processing
- Involvement of short-term and long-term memory

Parallelism



Juncture

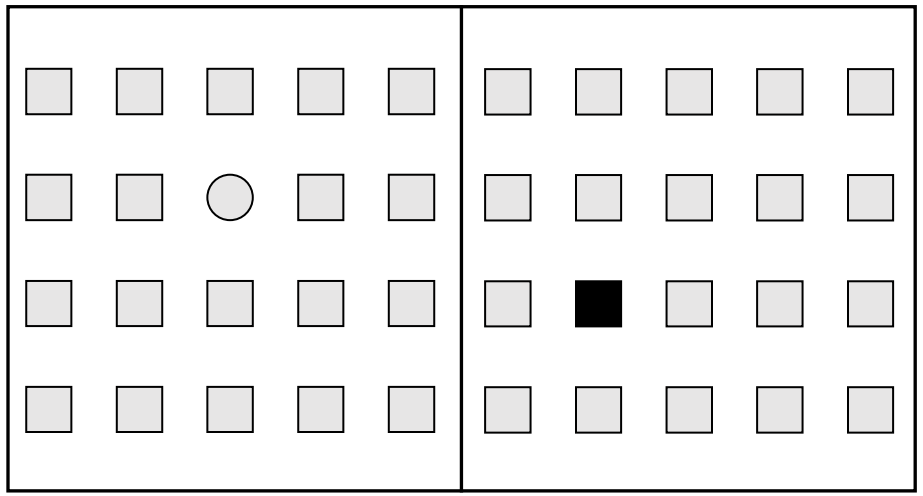


Ware 2001

Two Stages of Visual Perception

Coding with combinations of features

- Most of the combinations are not perceived preattentively, even if isolated features are.
- Shape and grey value as isolated variables are perceived preattentively. Their combination, however, requires „reading“.



Ware 2001

Color Perception

Data Types and Visualization Parameters

Visualization of Quantitative Data

- Measured/simulated values represent numbers (land prices in different regions)
- Vis. goal: comparison of numbers
- Appropriate: position, length, angle, area
- Inappropriate: texture, shape

Visualization of Ordinal Data

- There is an order, but values are not quantitative (e.g. days of the week, month)
- Vis. goal: (qualitative) comparison
- Appropriate: position, brightness and saturation
- Inappropriate: texture, shape

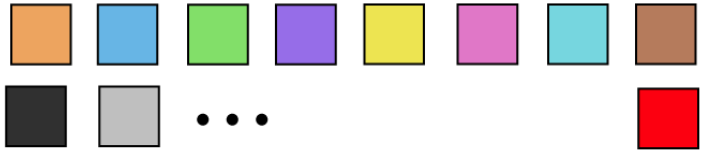
Visualization of Nominal Data

- no order, data represent categories (e.g. car manufacturers and countries)
- Vis. goal: categorization (preattentively)
- Appropriate: position, hue and texture
- Inappropriate: angle, area

[Bertin, 1983]

Position, Size and Orientation

Variables for the visualization of information (Stolte, 2002).

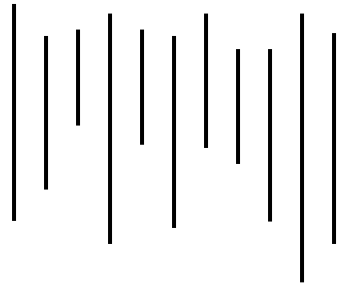
property	marks	ordinal/nominal mapping	quantitative mapping
shape	glyph		
size	rectangle, circle, glyph, text		
orientation	rectangle, line, text		
color	rectangle, circle, line, glyph, y-bar, x-bar, text, gantt bar		

Position, Size and Orientation

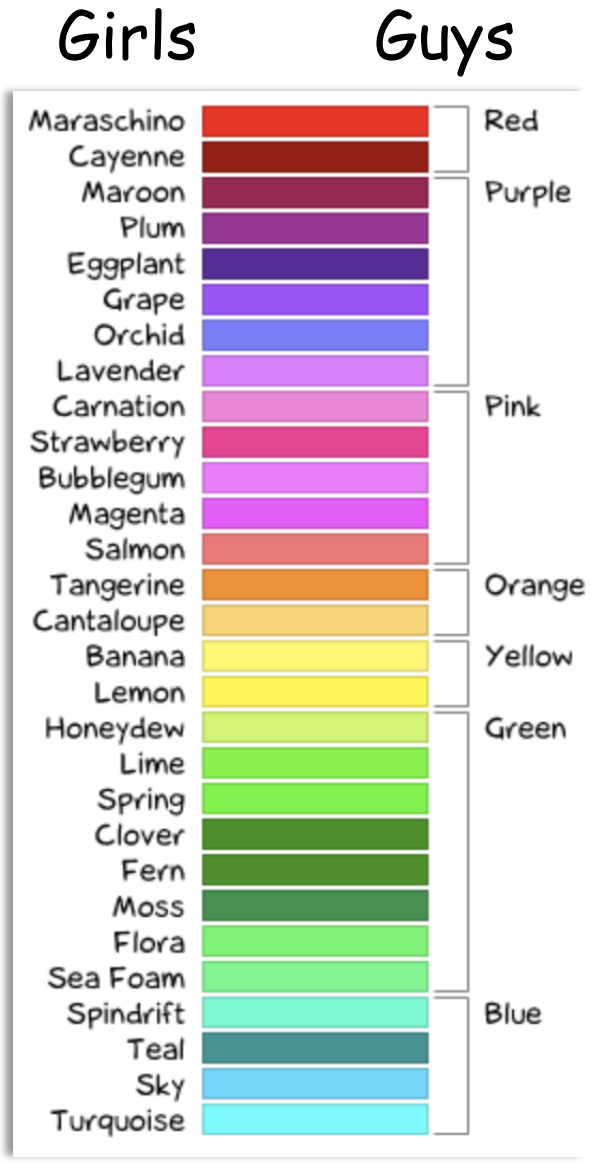
What has to be considered?

- Perception of lengths is **logarithmic** (differences between longer structures should be larger to be recognizable).

  Example: Lines with length from 0.5 – 1.4



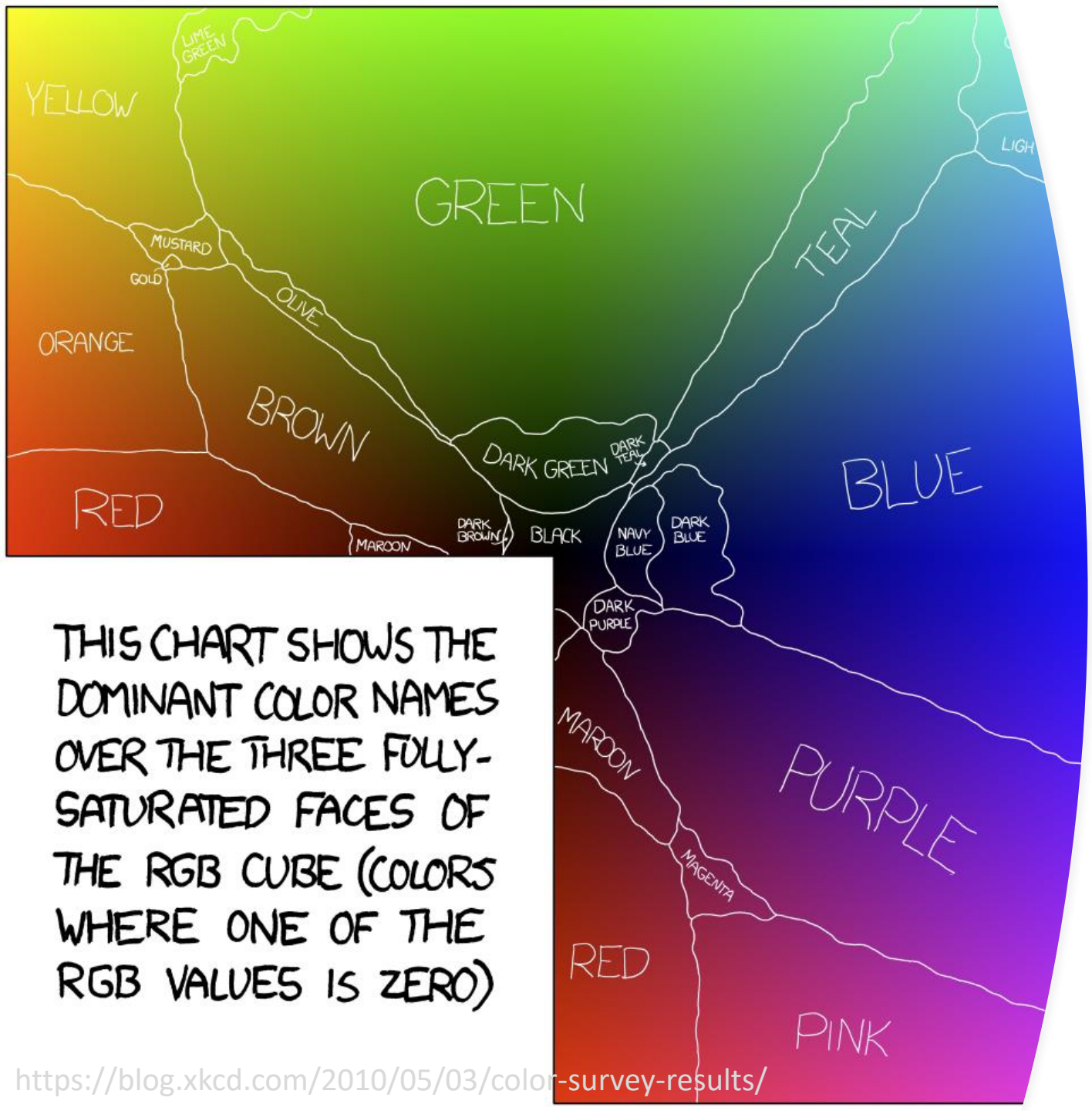
- **Perception of angles is less precise** close to 0 and 90 degrees, obtuse angles are overestimated, acute angles are underestimated.
- If circles encode quantitative data, they should be mapped to the **circle's area not to their radius**! Result of empirical tests: r should be chosen such that $x = \left(2\pi r^2\right)^{0.7}$
  Source: Schumann/Müller [2000]
- No more than four to five different sizes should be used when visualizing ordinal data (Bertin, 1983)



Color Naming

- Gender Specific?

https://blog.xkcd.com/2010/05/03/color-survey-results/

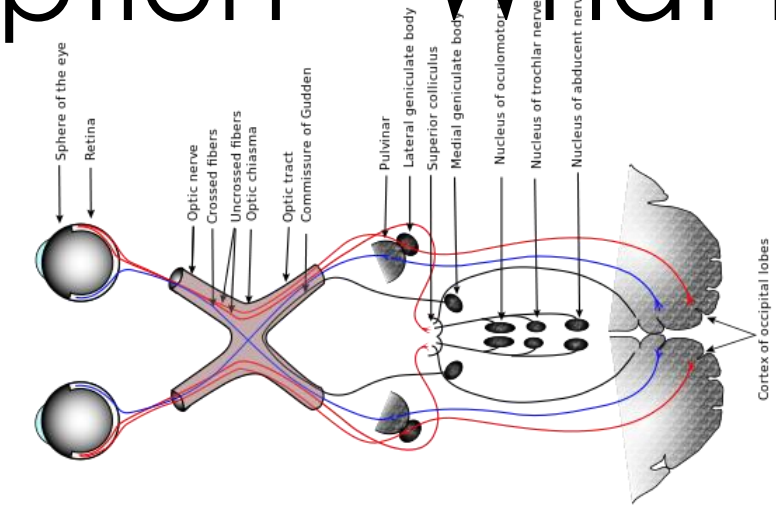


https://blog.xkcd.com/2010/05/03/color-survey-results/

Color Naming: Name Boundaries

- Associate and group colors together, often using the name the users assign to the colors

Color Perception – What is Color?



"Green"

Physical World

- Lights
- Objects
- Surfaces
- Reflections
- Shadows

Stimulus

Visual System

- Eye
- Retina
- Optic nerve
- Visual cortex

Signals

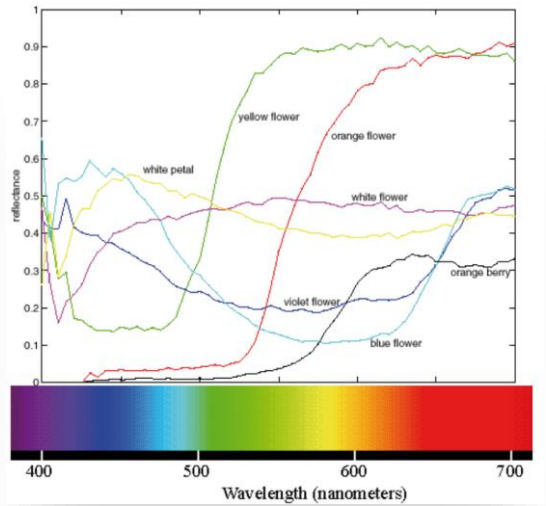
Interpretation

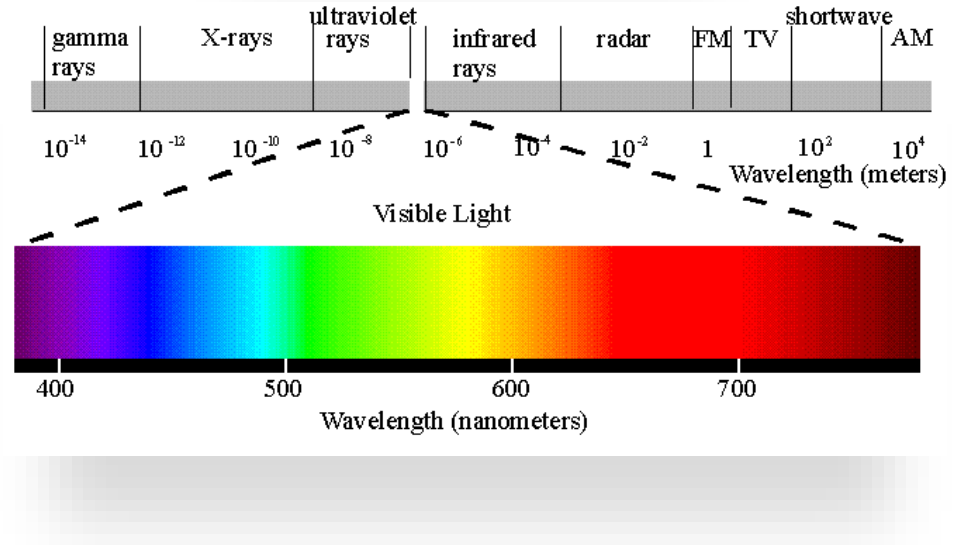
- Red, green, yellow
- Bright, dark, vivid, dull
- Warm, cold, pleasant, ugly

Physical World

What is light?

- Light is radiation in a range of wavelengths
- Light of a single wavelength is *monochromatic*
- Most colors are not monochromatic

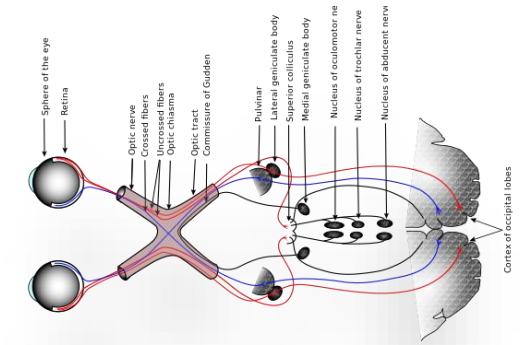


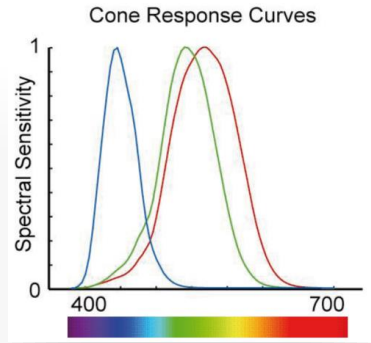


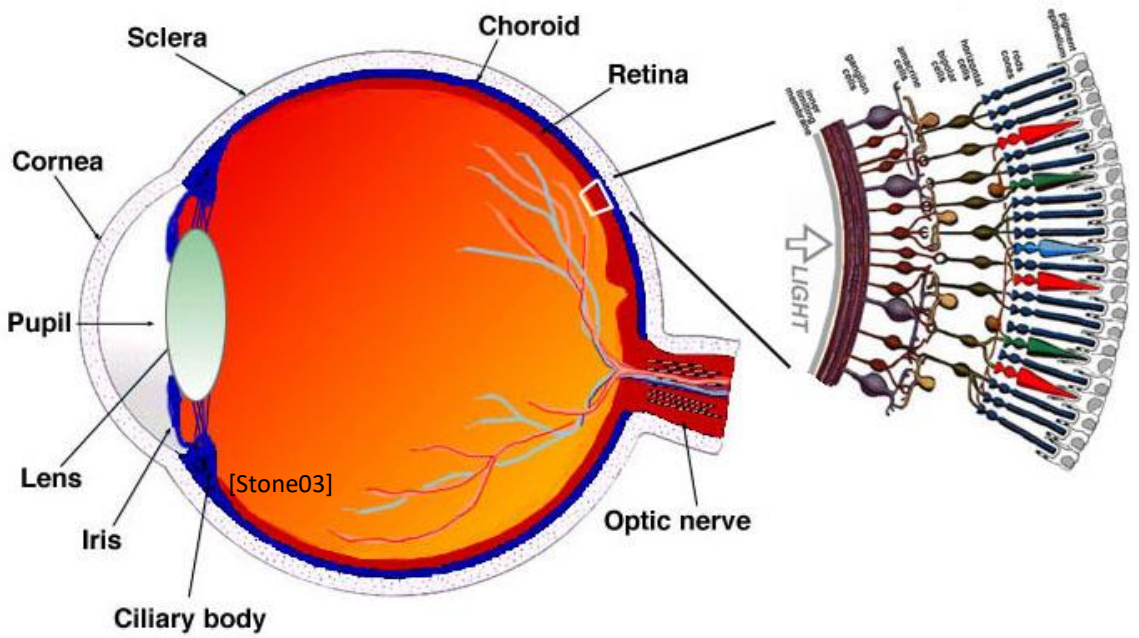
From [Willett14]

Visual System

- Receptors on the retina respond to light signal
- Two types of receptors:
  - Rods → gray values
  - Cones → colors
- Three kinds of cones:
  - Long
  - Middle
  - Short
- Transformation of response into nerve impulses sent to brain



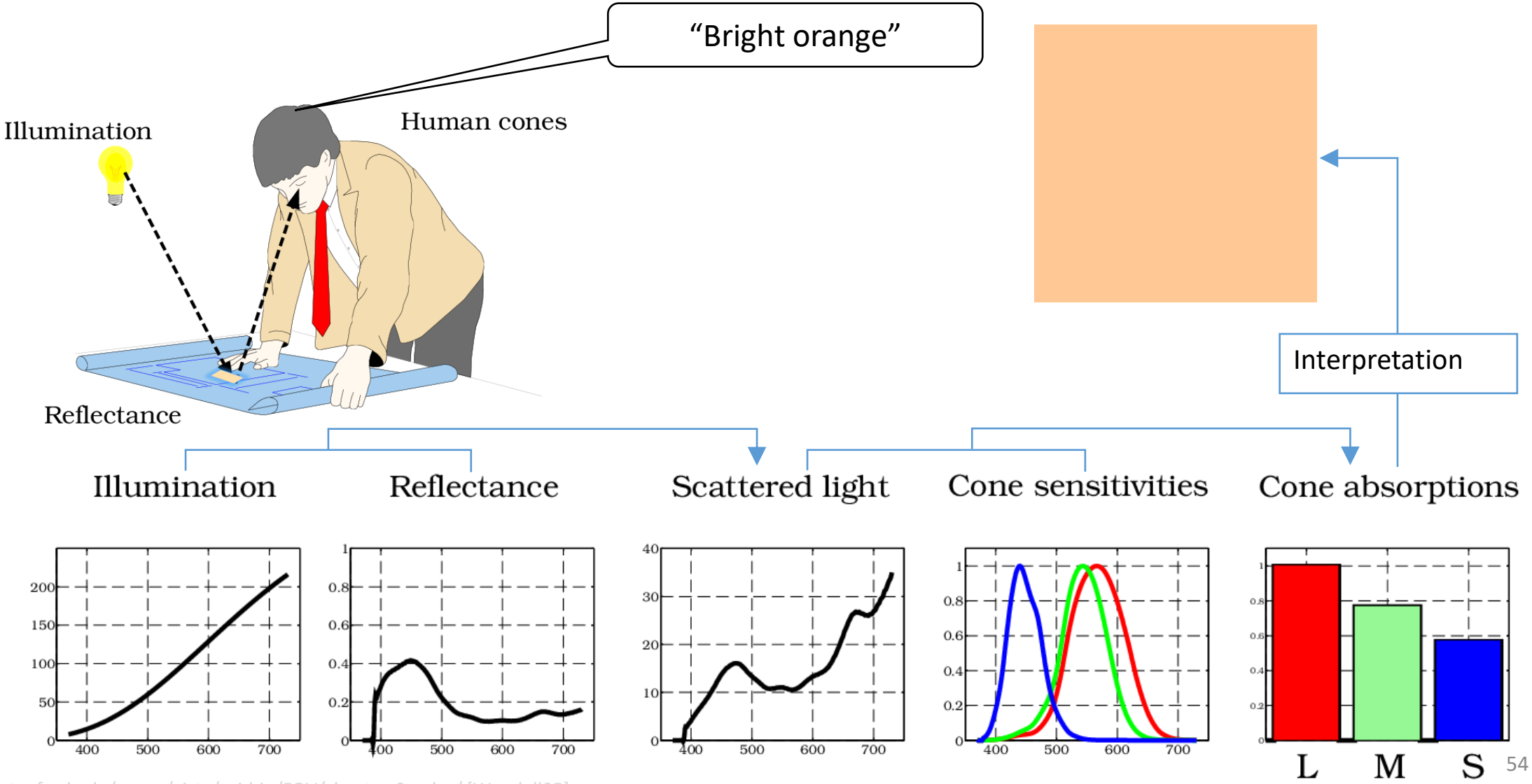




Simple Anatomy of the Retina by Helga Kolb

http://en.wikipedia.org/wiki/File:Gray722-svg.svg

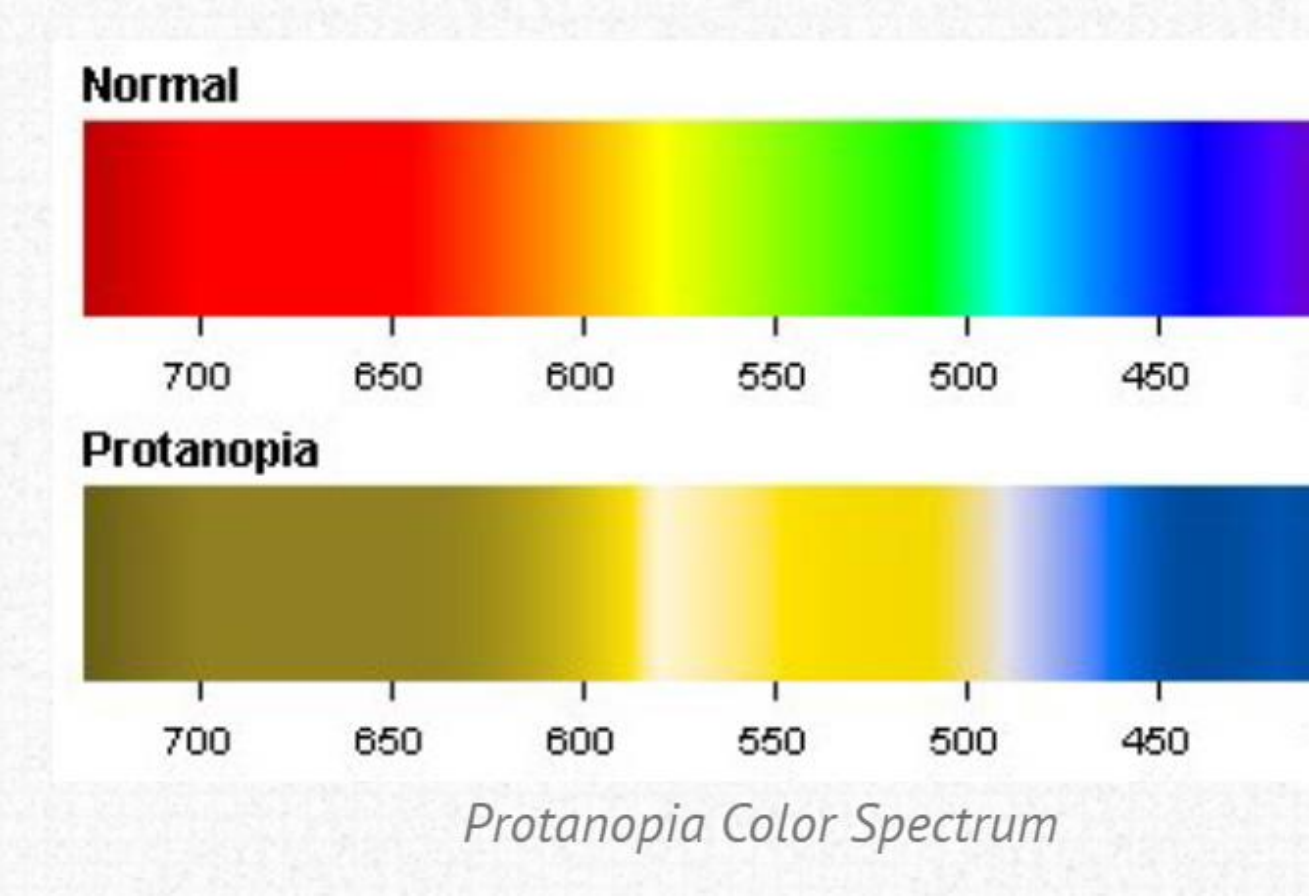
Spectral Image Formation



https://www.stanford.edu/group/vista/cgi-bin/FOV/chapter-9-color/ [Wandell95]

Color Deficiency

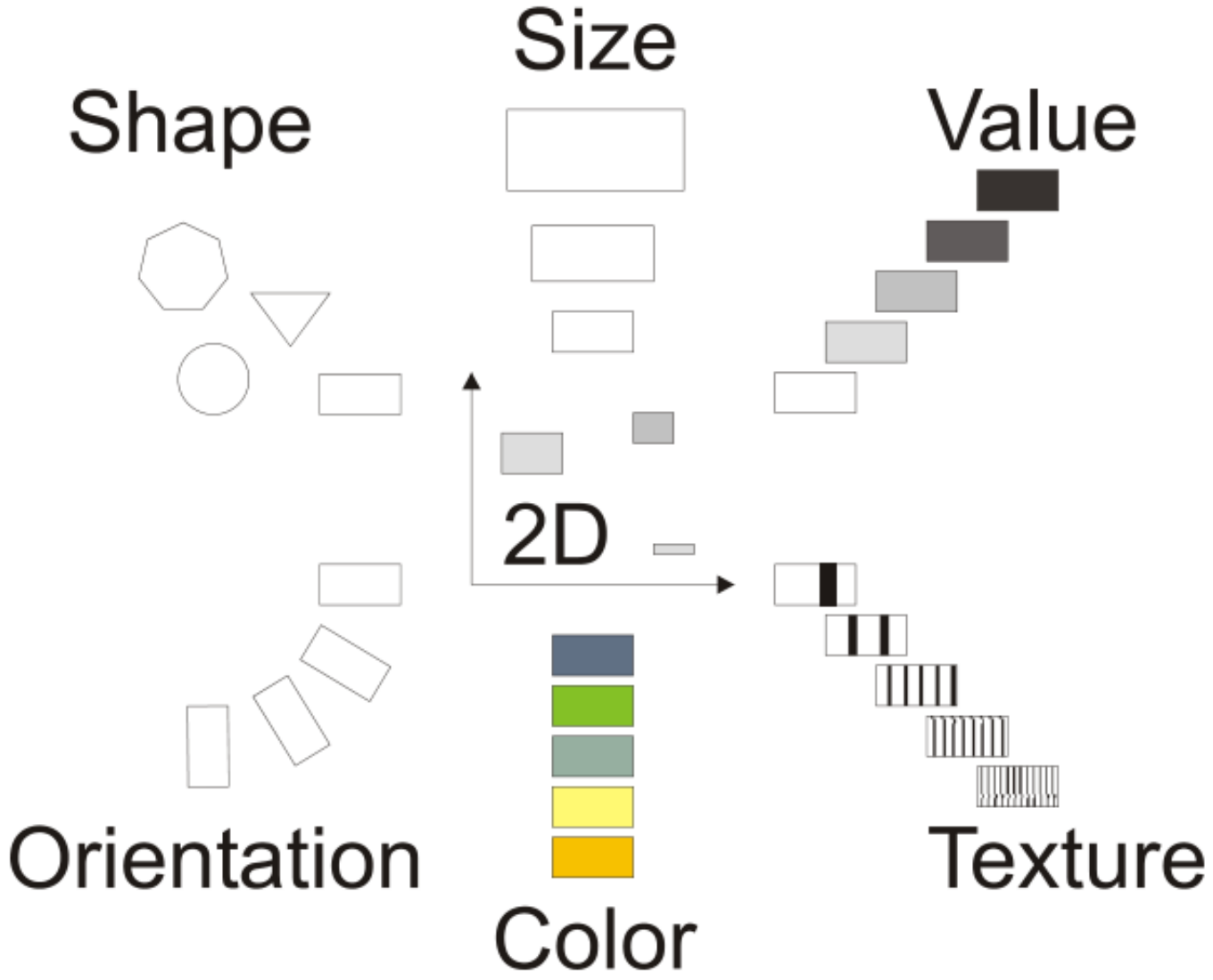
- Red-green color deficiency is most common form: *Protanopia* (red) and *Deuteranopia (green)*
- Protans have difficulties to distinguish between **blue and green** colors and between **red and green** colors
- Other forms exist as well, e.g., *Tritanopia* (blue)
- ~7% of male population is color-deficient



Protanopia Color Spectrum

Perception of Visual Encodings

Visual Variables Applicable to Marks



[Bertin67]

Perception of Visual Encodings

- Elementary graphical perception tasks designed by William S. Cleveland in the 1980s
- Controlled experiments to determine how effectively people judge changes in visual features
- Focus on quantitative data
- Tested variables:
  - Hue, saturation, density (value)
  - Angle, slope
  - Area (size), volume
  - Length
  - Position

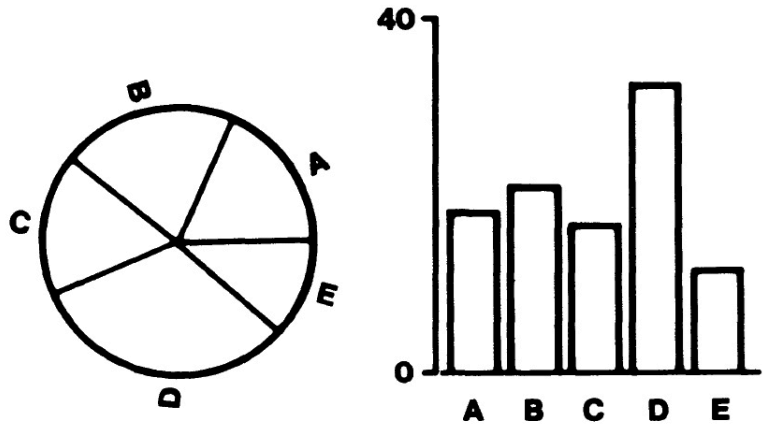
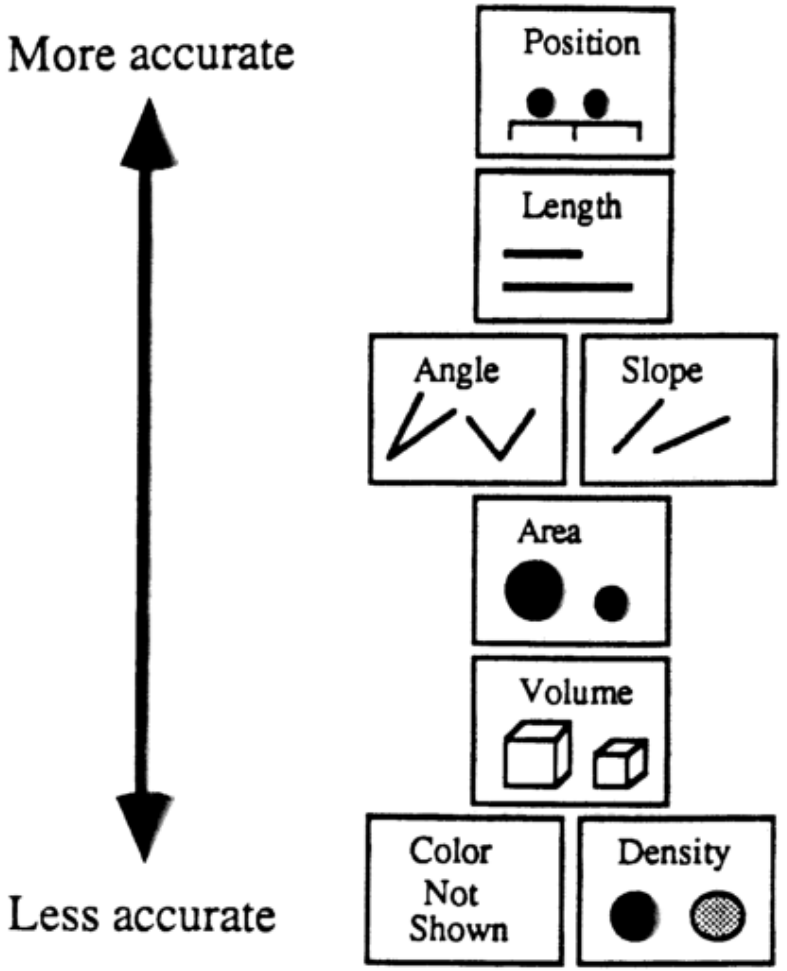


Figure 3. Graphs from position–angle experiment.

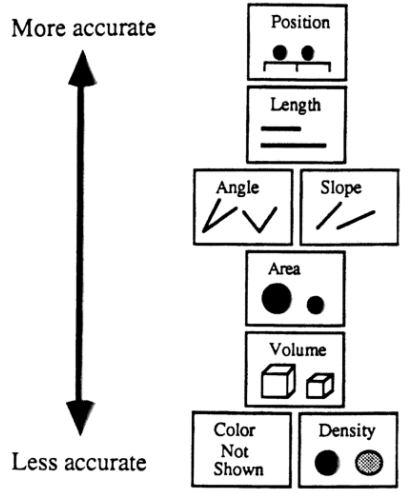
[Cleveland84]

Perception of Visual Encodings

Cleveland's results [Cleveland84]

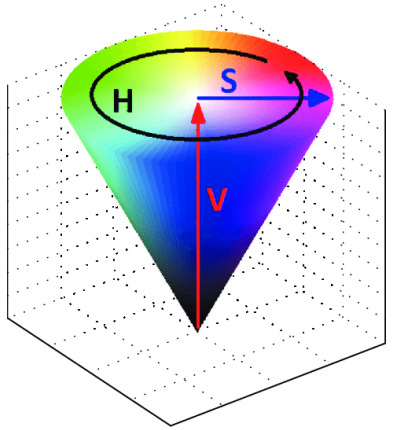


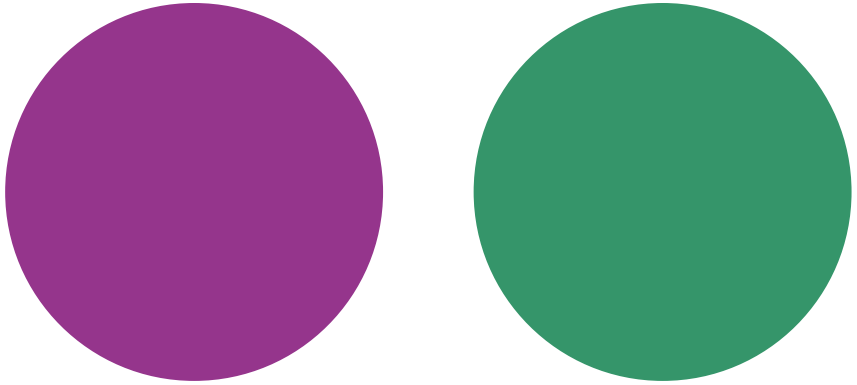
Perception of Visual Encodings



Color hue

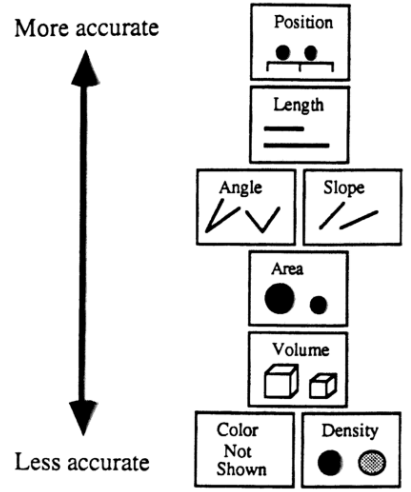
- What percentage in hue is the right from the left (=100%)?





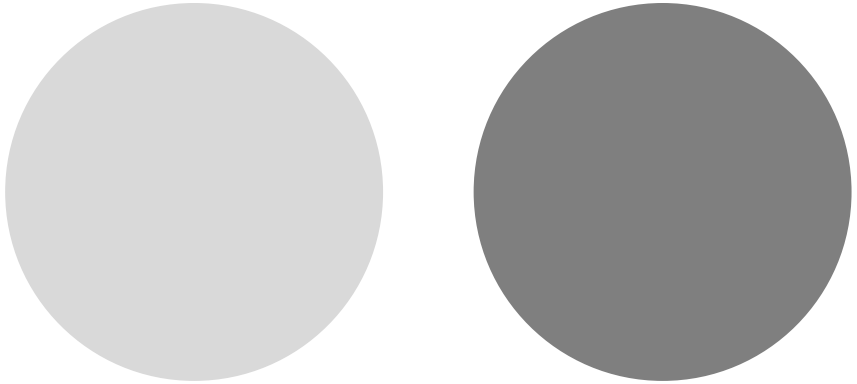
50%

Perception of Visual Encodings



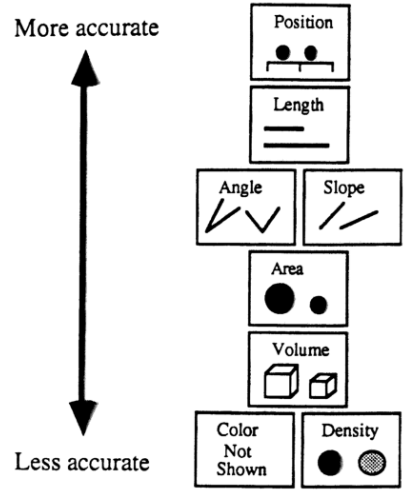
Density (value)

- What percentage in value is the right from the left (=100%)?



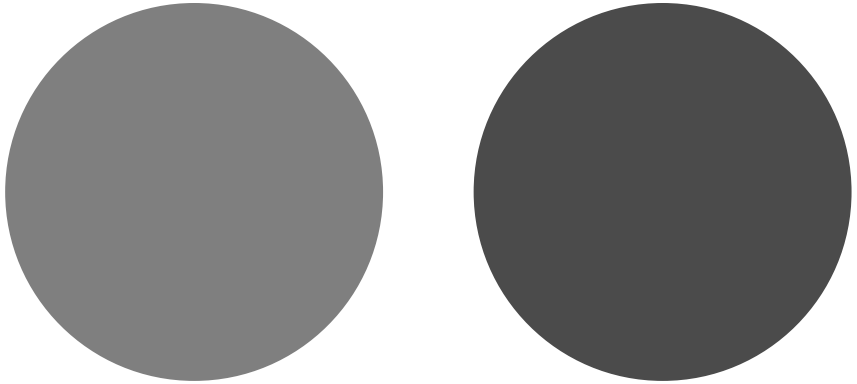
~59%

Perception of Visual Encodings



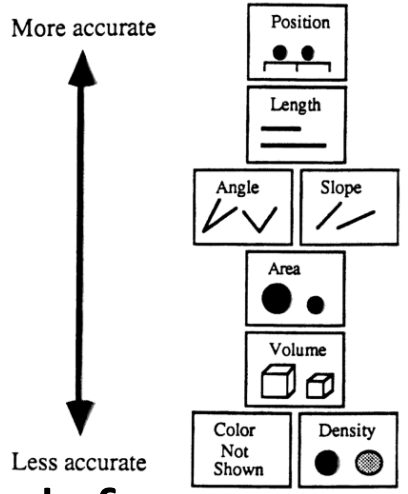
Density (value)

- What percentage in value is the right from the left (=100%)?



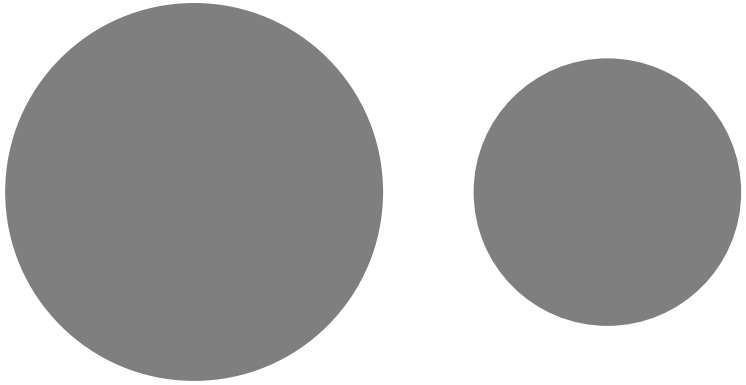
~59%

Perception of Visual Encodings



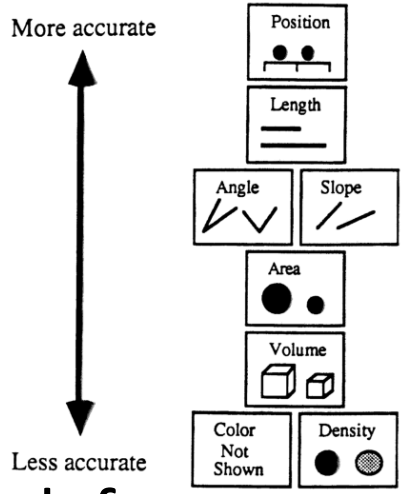
Area

- What percentage in size is the right from the left (=100%)?



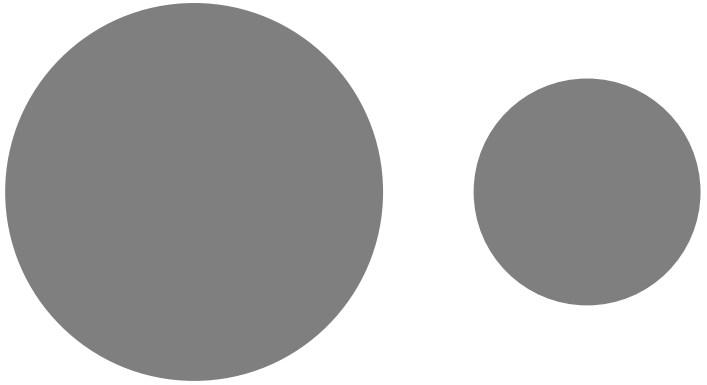
~50%

Perception of Visual Encodings



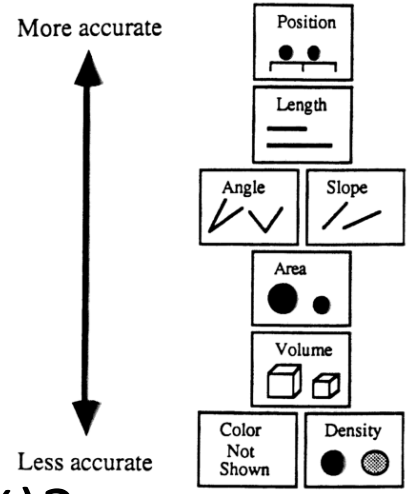
Area

- What percentage in size is the right from the left (=100%)?



~36%

Perception of Visual Encodings

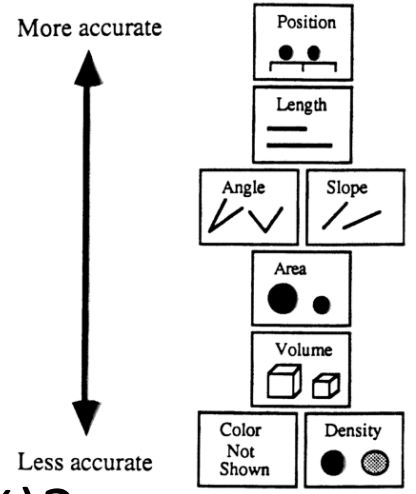


Length

- What percentage in length is the lower from the upper (=100%)?

66,6%

Perception of Visual Encodings



Length / Position

- What percentage in length is the lower from the upper (=100%)?

33,3%

Effectiveness of Visual Encodings

[Mackinlay86]

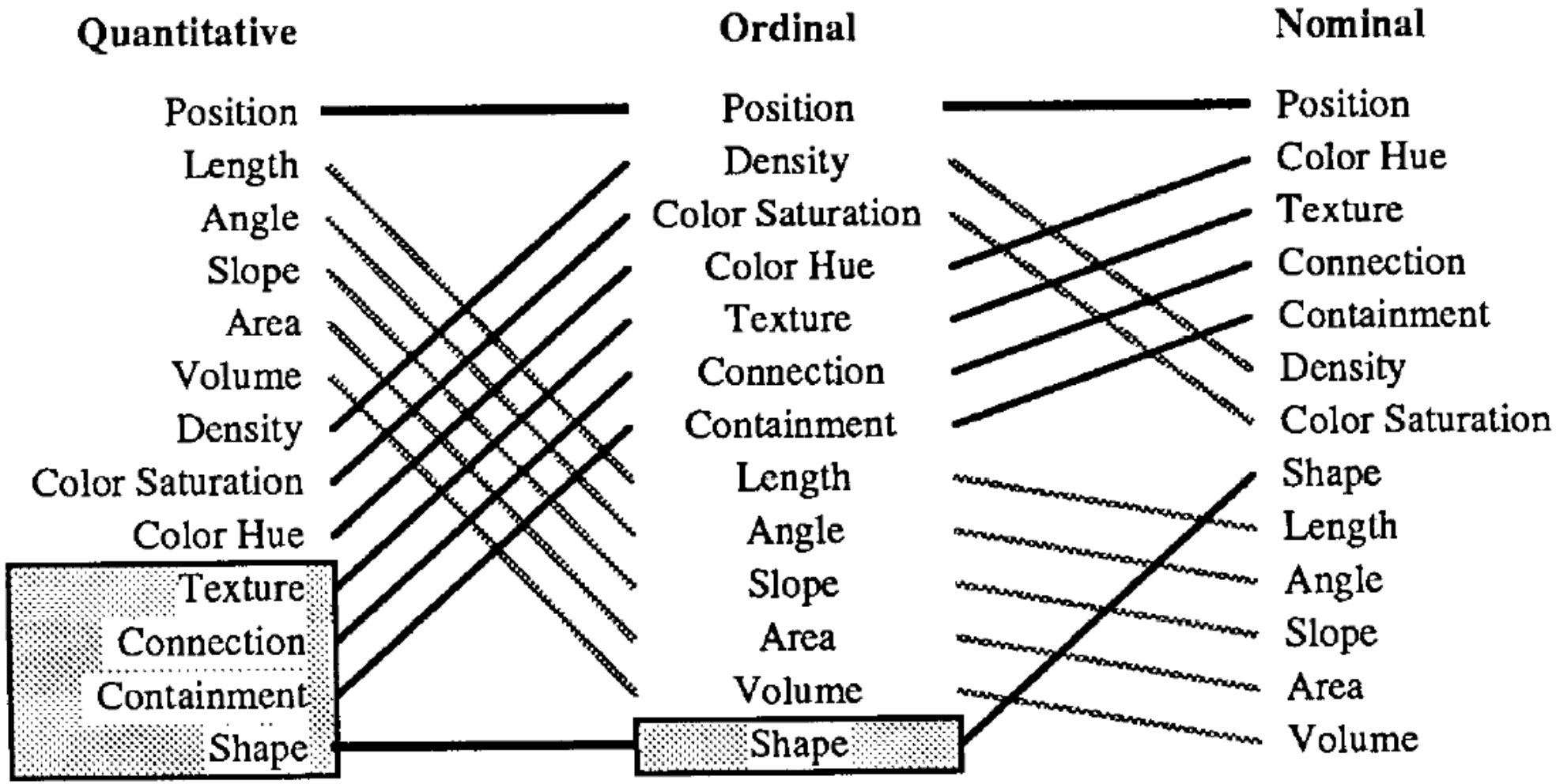


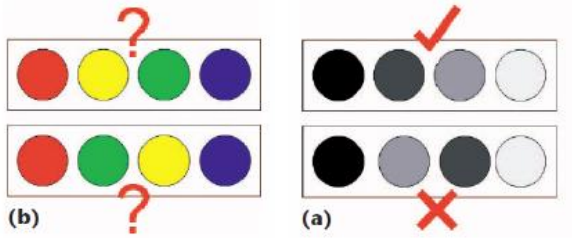
Fig. 15. Ranking of perceptual tasks. The tasks shown in the gray boxes are not relevant to these types of data.

Consequences for Visualization

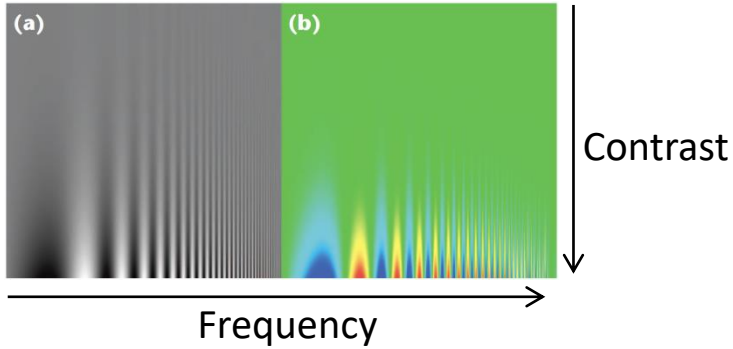
Rules for Using Color

"Rainbow Color Map (Still) Considered Harmful" [Borland07]

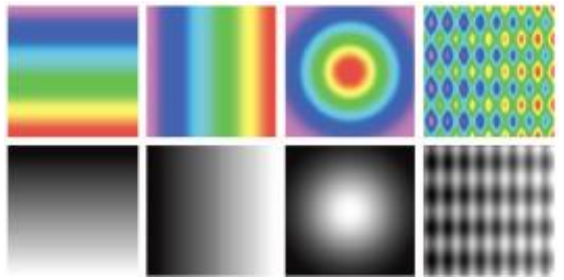
- Not perceptually ordered



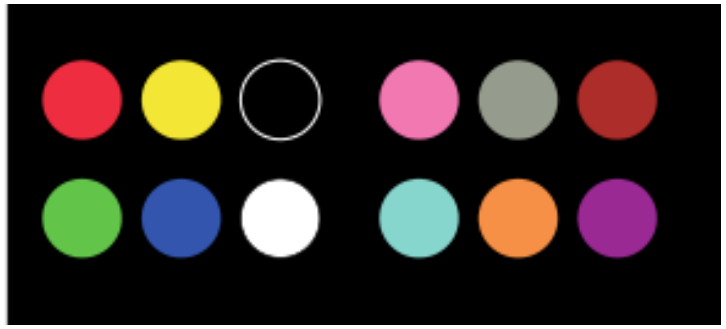
- Details only seen at higher contrasts



- Sharp transitions perceived in the data



Rules for Using Color



- Ensure high luminance contrast between foreground and background
- Use only a few distinct colors (~5 recommended)
- Consider application-specific conventions (e.g. red for high temperature or blue for low oxygen)
- Avoid red-green contrasts (color deficiency!)
- Beware of bad interactions

[Ware01]

Rules for Using Color

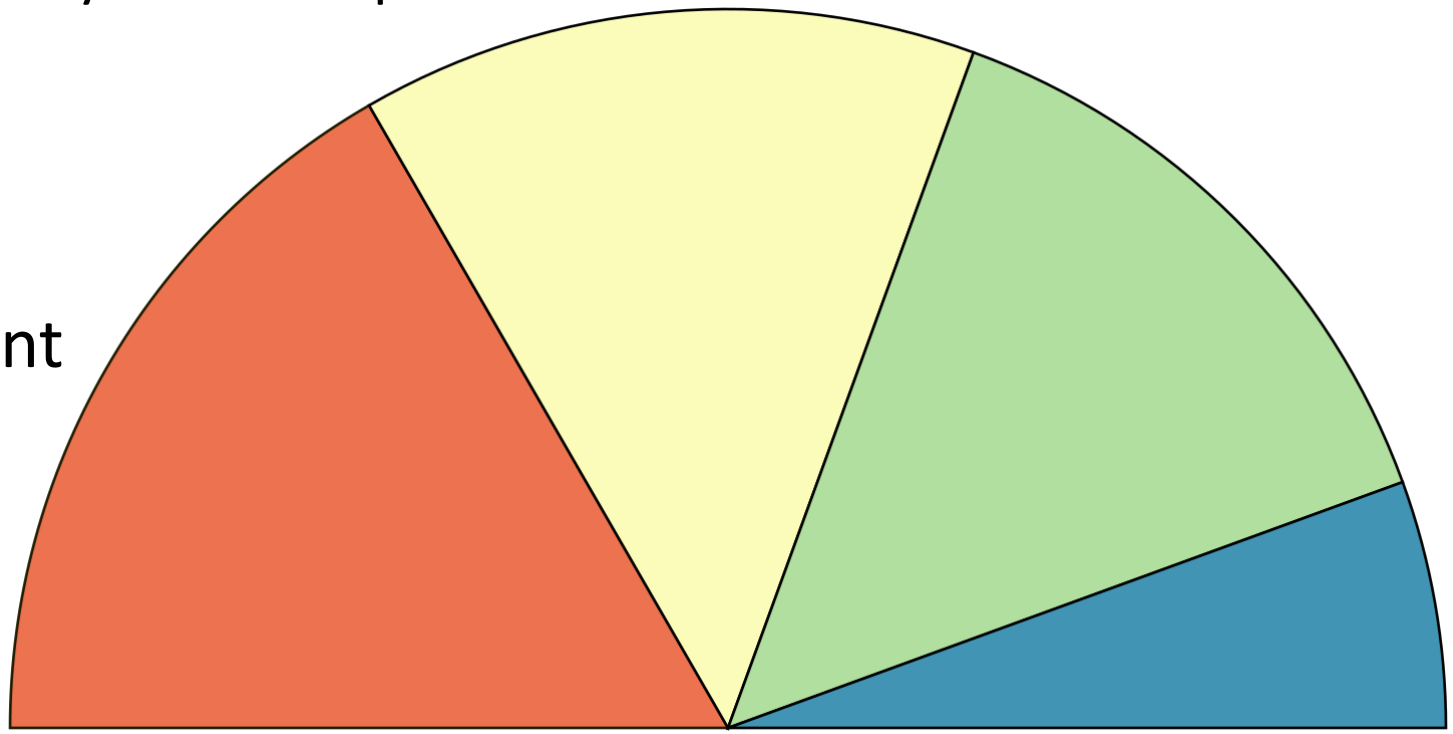
- Avoid strongly saturated colors, prefer pastel colors
- For ordinal and quantitative data
  - Use color scale that varies lightness
  - Shades of gray or shades of a single color work best

  - For diverging scales, use a lighter, desaturated value for the critical mid-point and darker hues for the ends

- Have a look at *ColorBrewer* for good color schemes

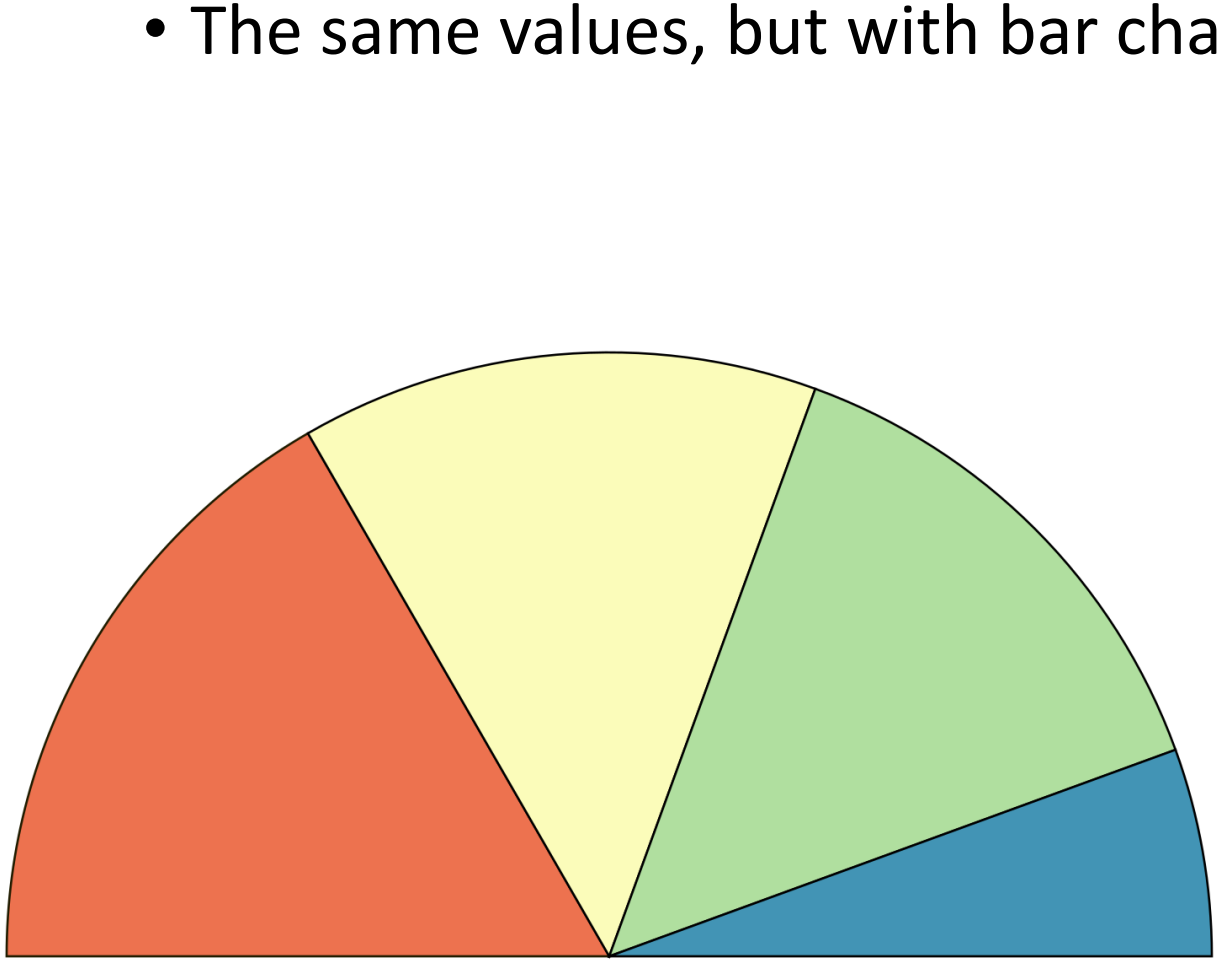
Pie Charts

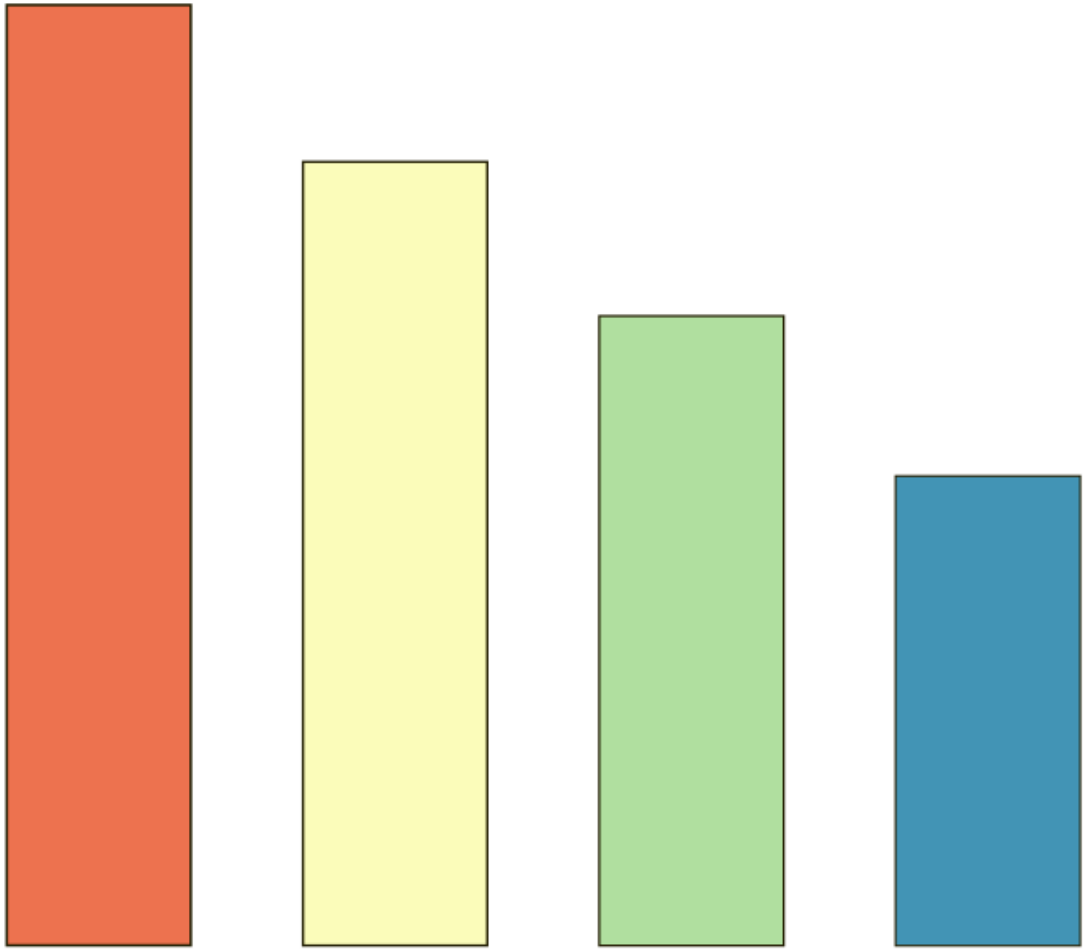
- Indicate different portions of a whole
- Quantitative comparison is more difficult compared to bar charts
  - Cannot be performed by means of preattentive vision
- Up to ~7 portions
- Example:
  budget planning,
  seating in a parliament

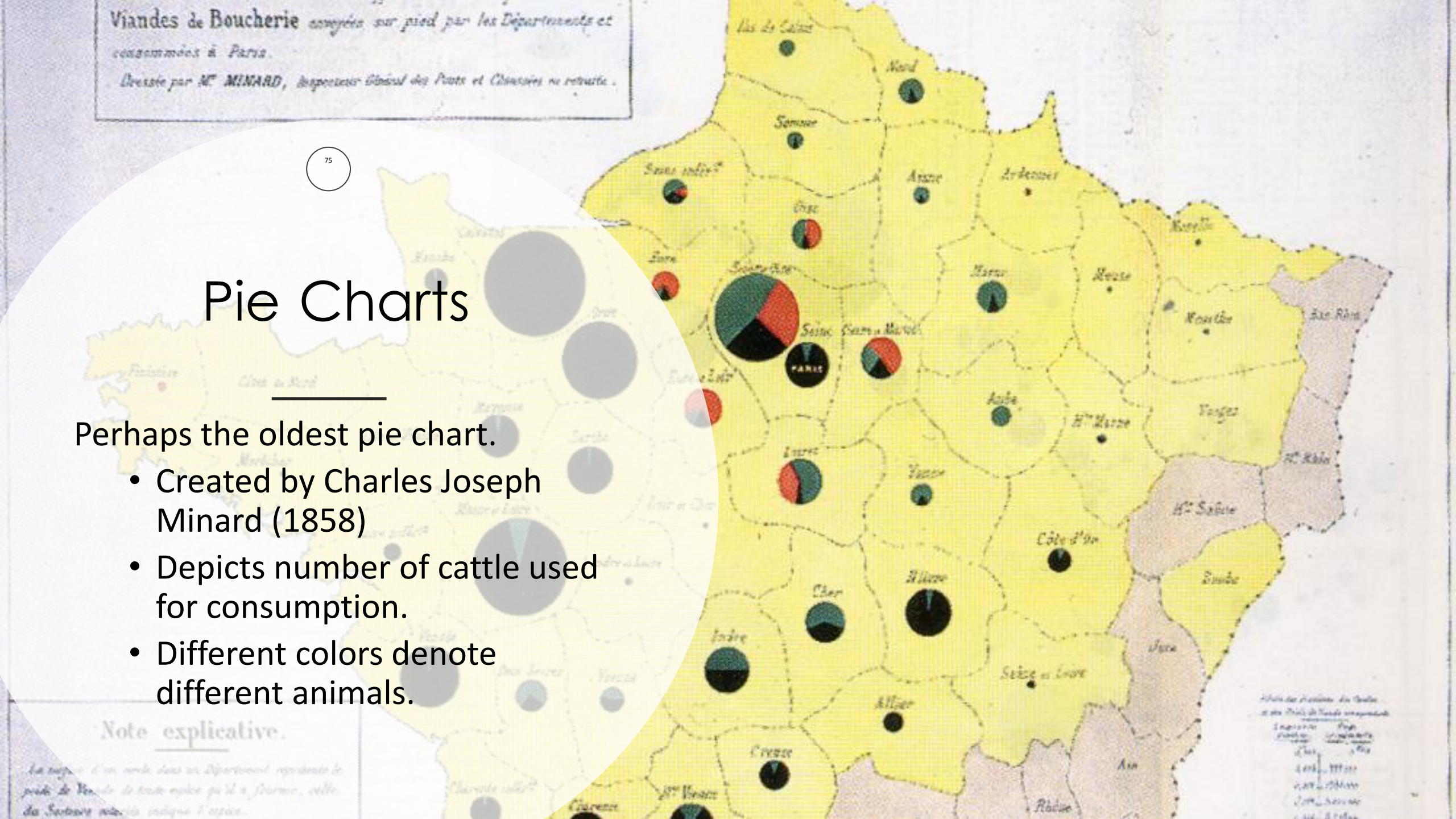


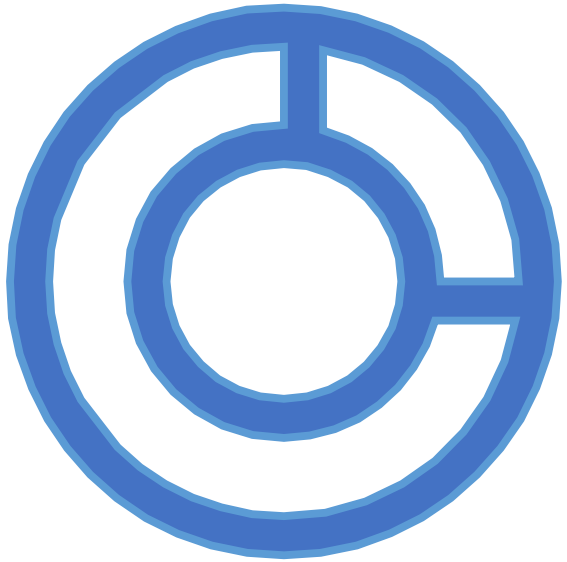
Pie Charts

- The same values, but with bar charts





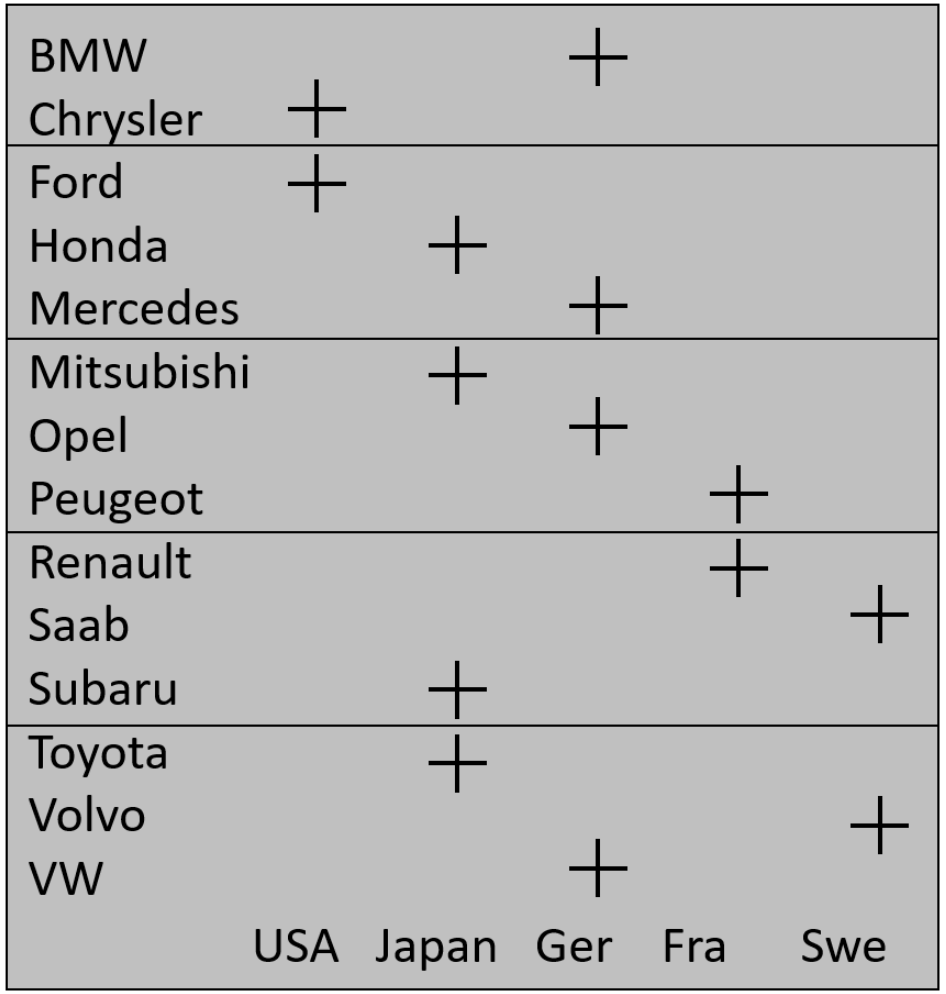

Viandes de Boucherie consommées sur pied par les Départements et consommées à Paris.
Dressée par M. MINARD, Inspecteur Général des Ponts et Chaussées en retraite.
75
Pie Charts
Perhaps the oldest pie chart.
Created by Charles Joseph Minard (1858)
Depicts number of cattle used for consumption.
Different colors denote different animals.
PARIS
Note explicative.

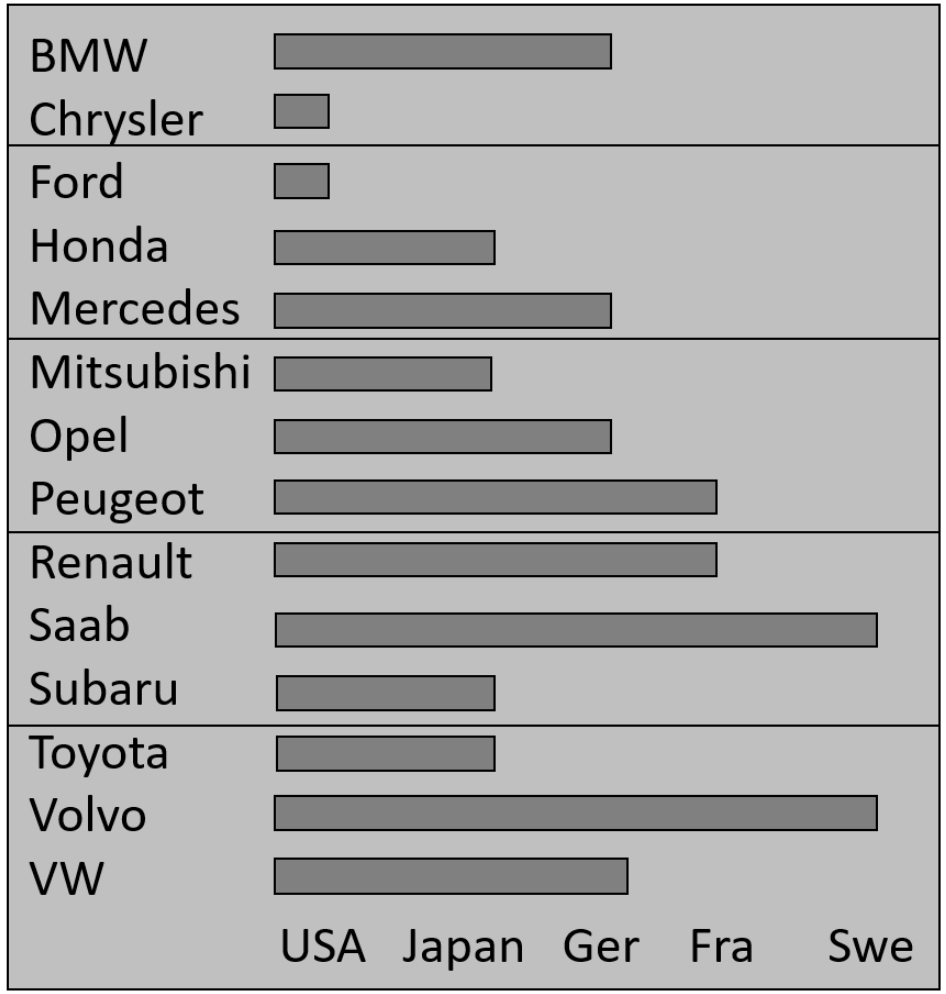


Pie Charts – Discussion

- Highly popular in mass media.
- Among statisticians, bar charts are favored over pie charts.
- Judgments of areas or angle are more difficult and error-prone than judgments of length. (Friendly, 1995, Tufte, 1983)
- Later experiments confirmed this (Cleveland, 1984 and Cleveland, 1986)

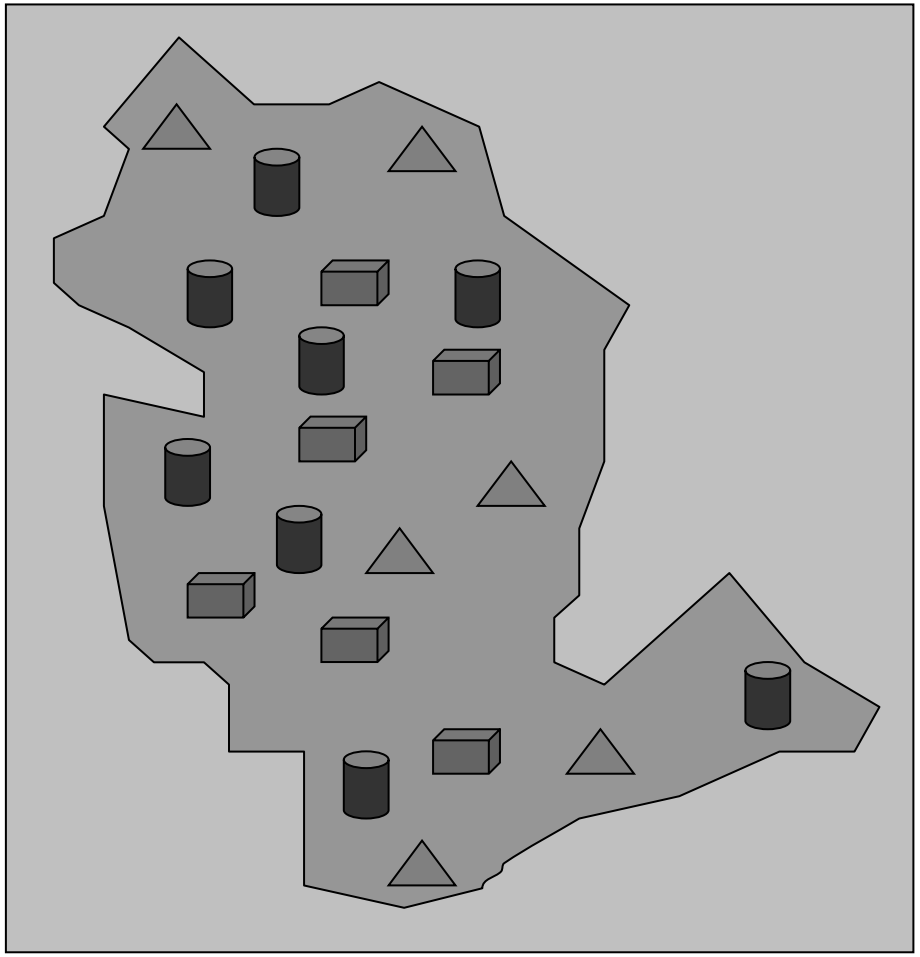
Visualization Quality Criteria: Expressiveness

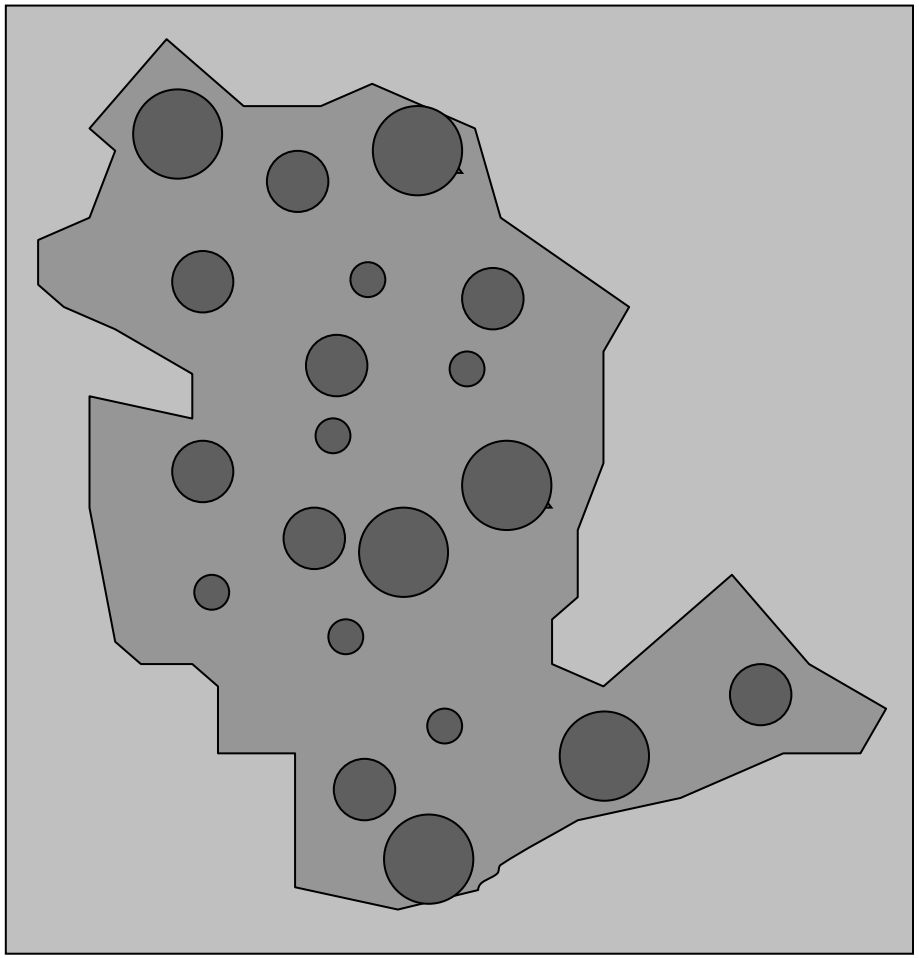




[Schumann and Müller 2000]

Visualization Quality Criteria: Effectiveness





[Schumann and Müller 2000]

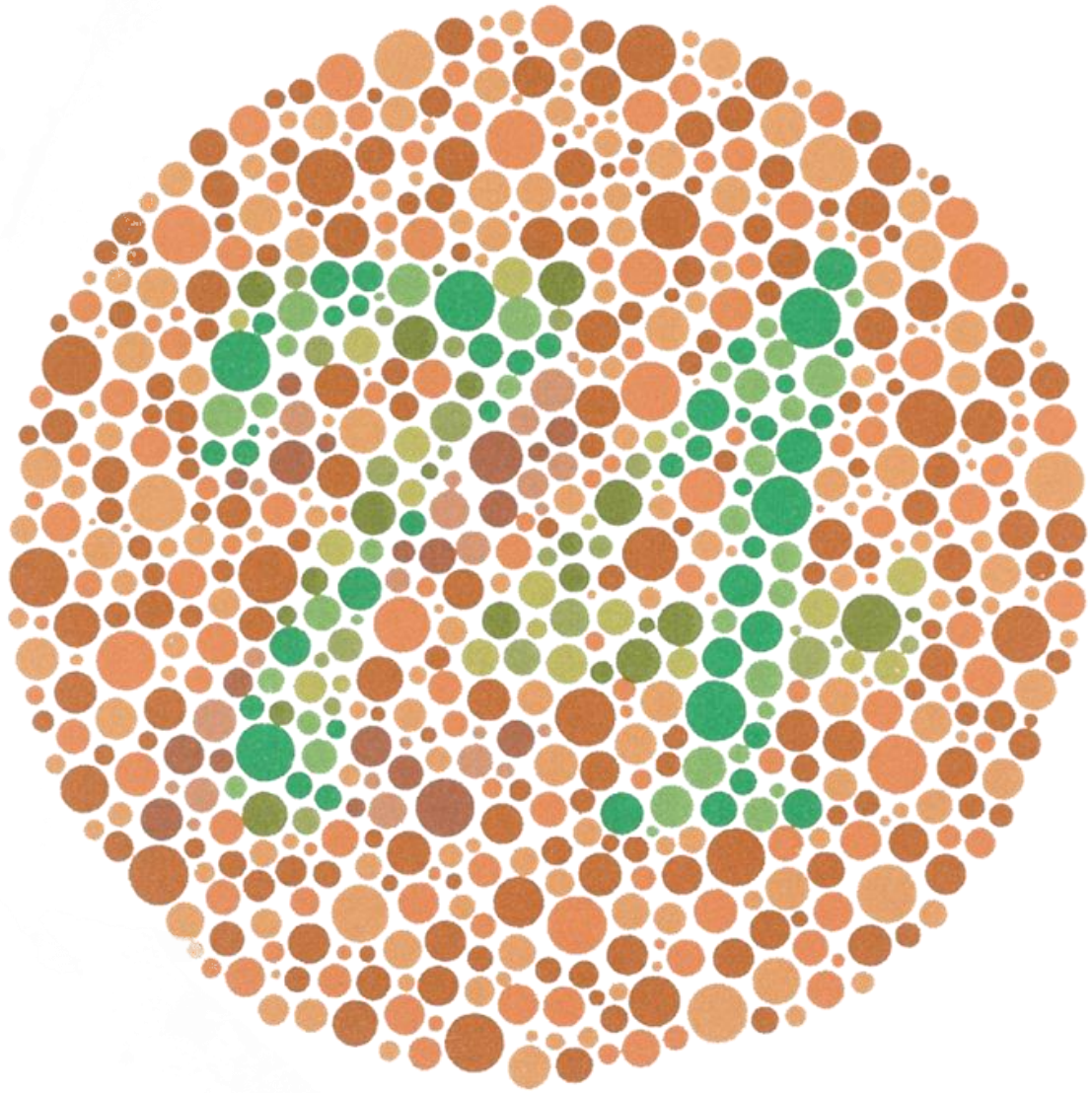
Mapping to Color

Possible fields of applications for color:

- To discriminate or emphasize elements/regions,
- To show objects in a natural color,
- To compare ordinal and quantitative values (how can colors convey “less than” ?)

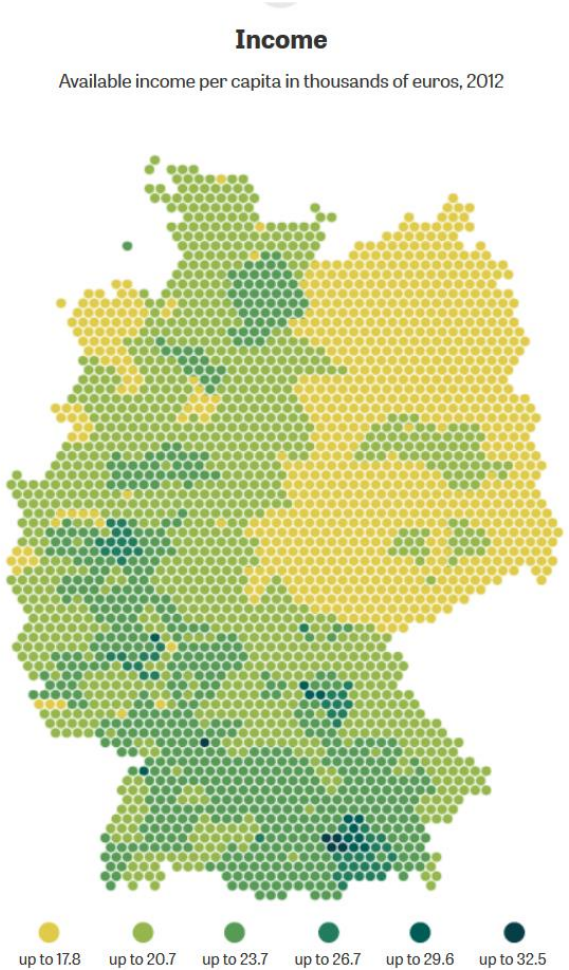
Problems:

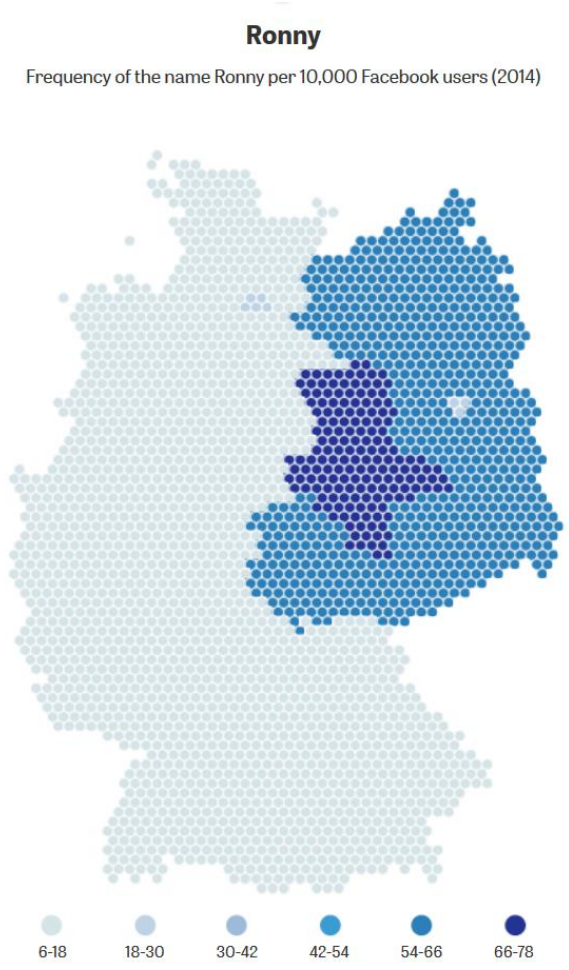
- Persons with limited color vision,
- Non perception-oriented color maps



Mapping Data to Color

From a story on the German reunification and existing differences after 25 years
([Link])





Mapping Data to Texture

Textures for the Classification of Data.

Several attributes such as orientation and density are perceived preattentively (according to Texton-theory, Julesz, 1981)

[Ware 20

Visualization Examples

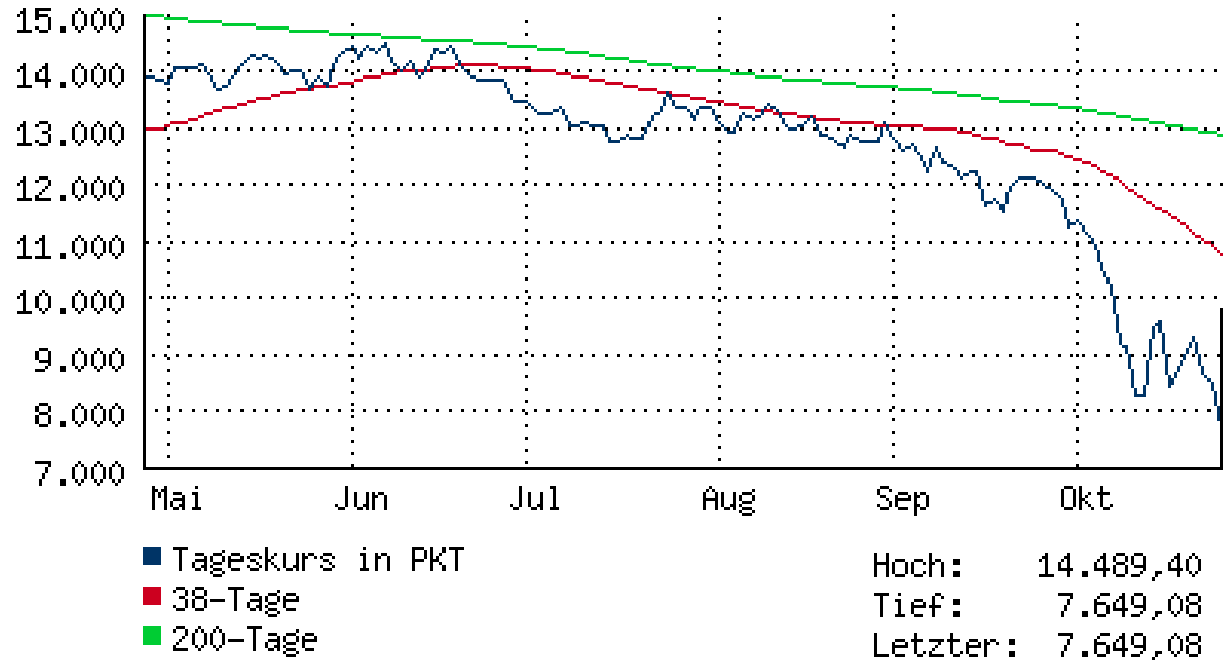
Selected application areas:

- Visualization of financial data, e.g., stock prices
- Flow visualization
- Medical visualization
- Visualization of geospatial data

Visualization Examples: Financial Data

Nikkei-Index, 2008

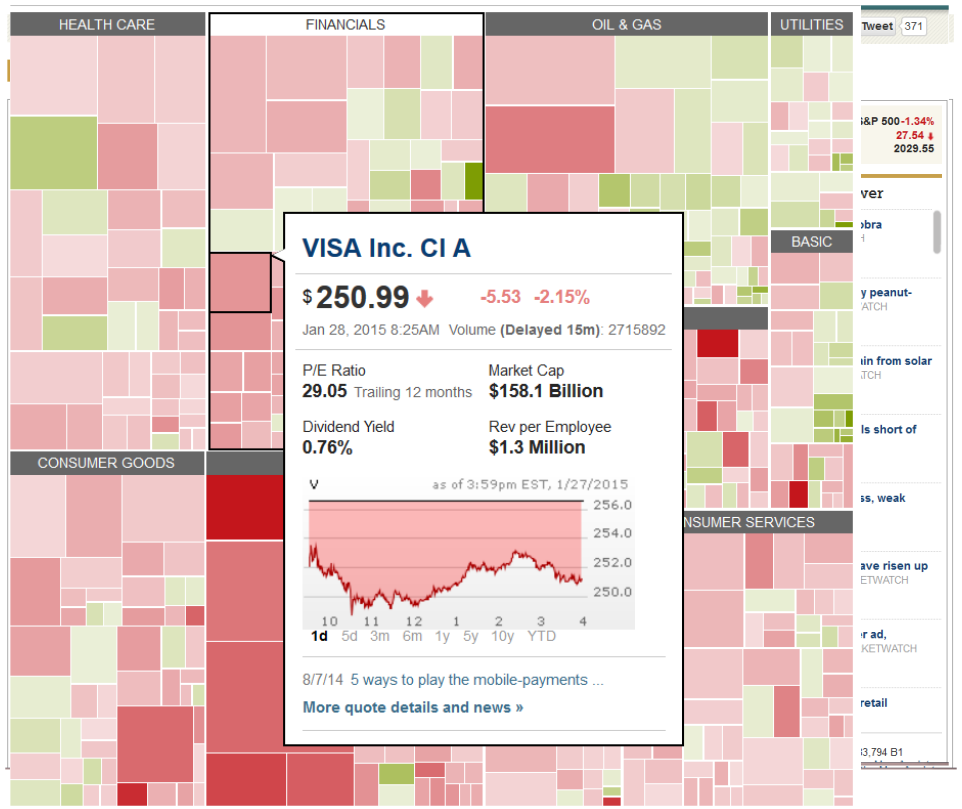
- Averaging over certain intervals (38 days, 200 days) has a smoothing effect and helps to assess medium- and long-term trends.



Visualization Examples: Financial Data

Map of the Market: http://www.marketwatch.com/tools/stockresearch/marketmap

Mission statement: „mission of the magazine was to make complicated financial data understandable”



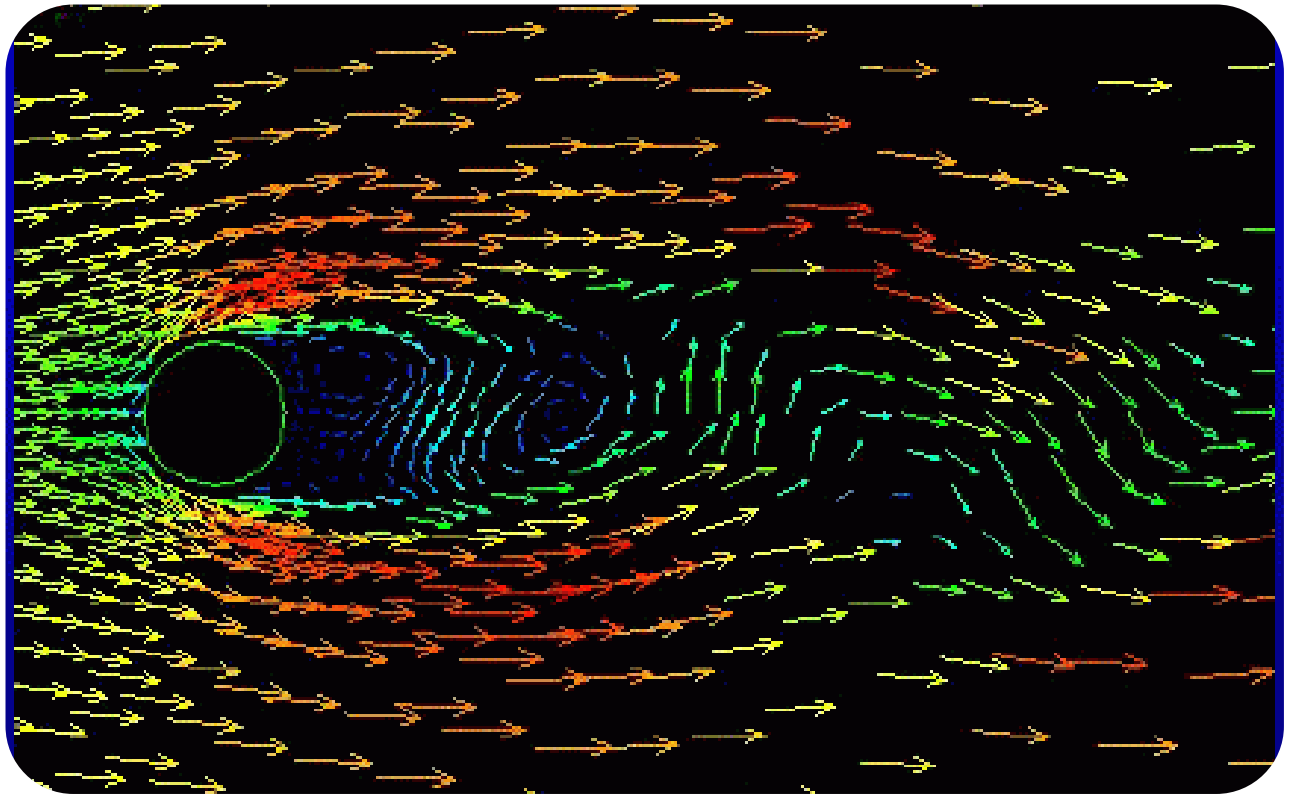
Starting from an overview visualization more and more details are shown.

Basic vis. technique: Tree map

Flow Visualization

Data: 2D vector data resulting from a simulation

Mapping: arrows indicate flow direction, color encodes speed

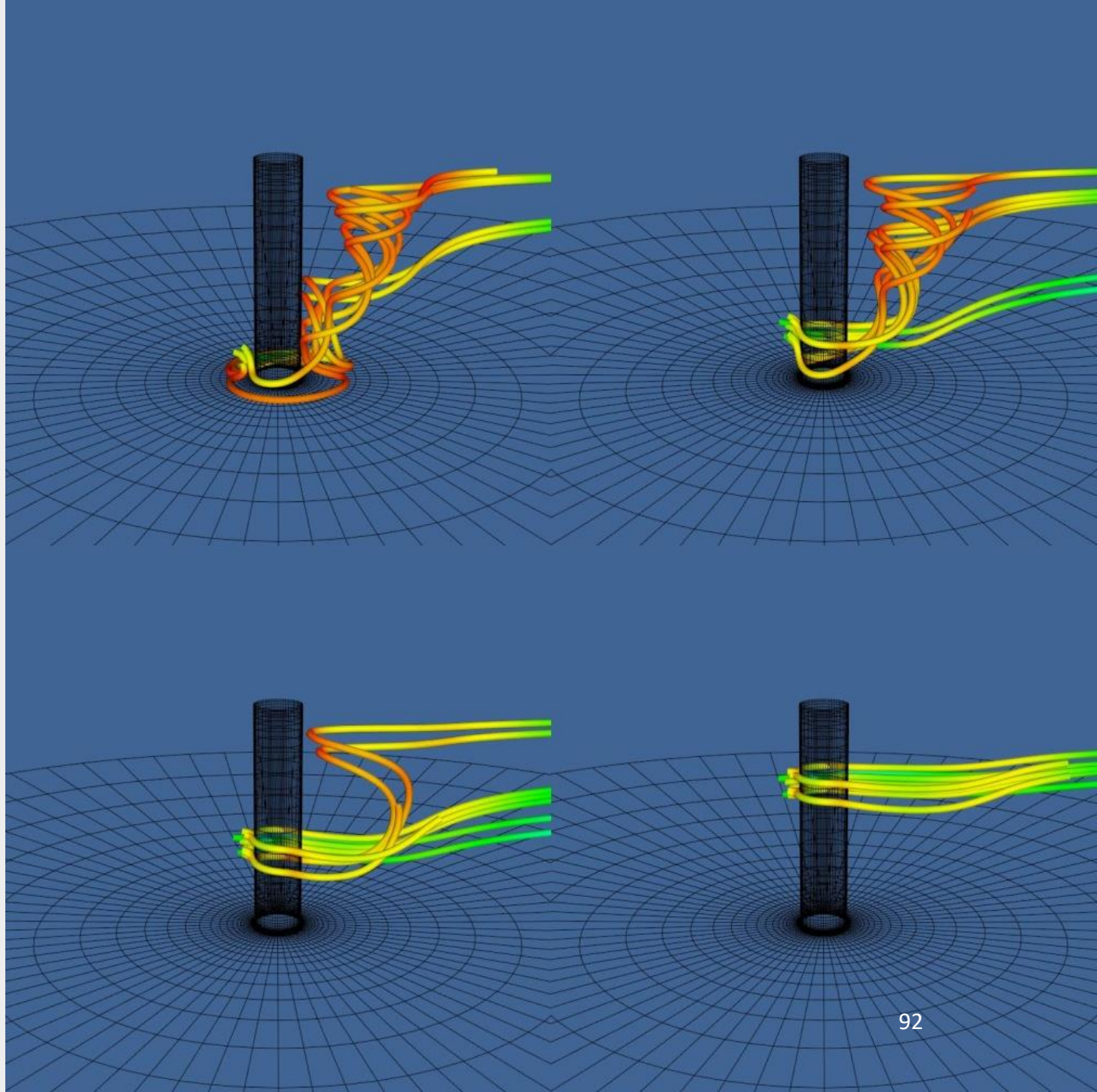


Flow Visualization

Data: 3D vector data resulting from CFD analysis (Computational Fluid Dynamics)

Mapping: streamtubes (indicate direction of flow) and color (encodes magnitude of flow)

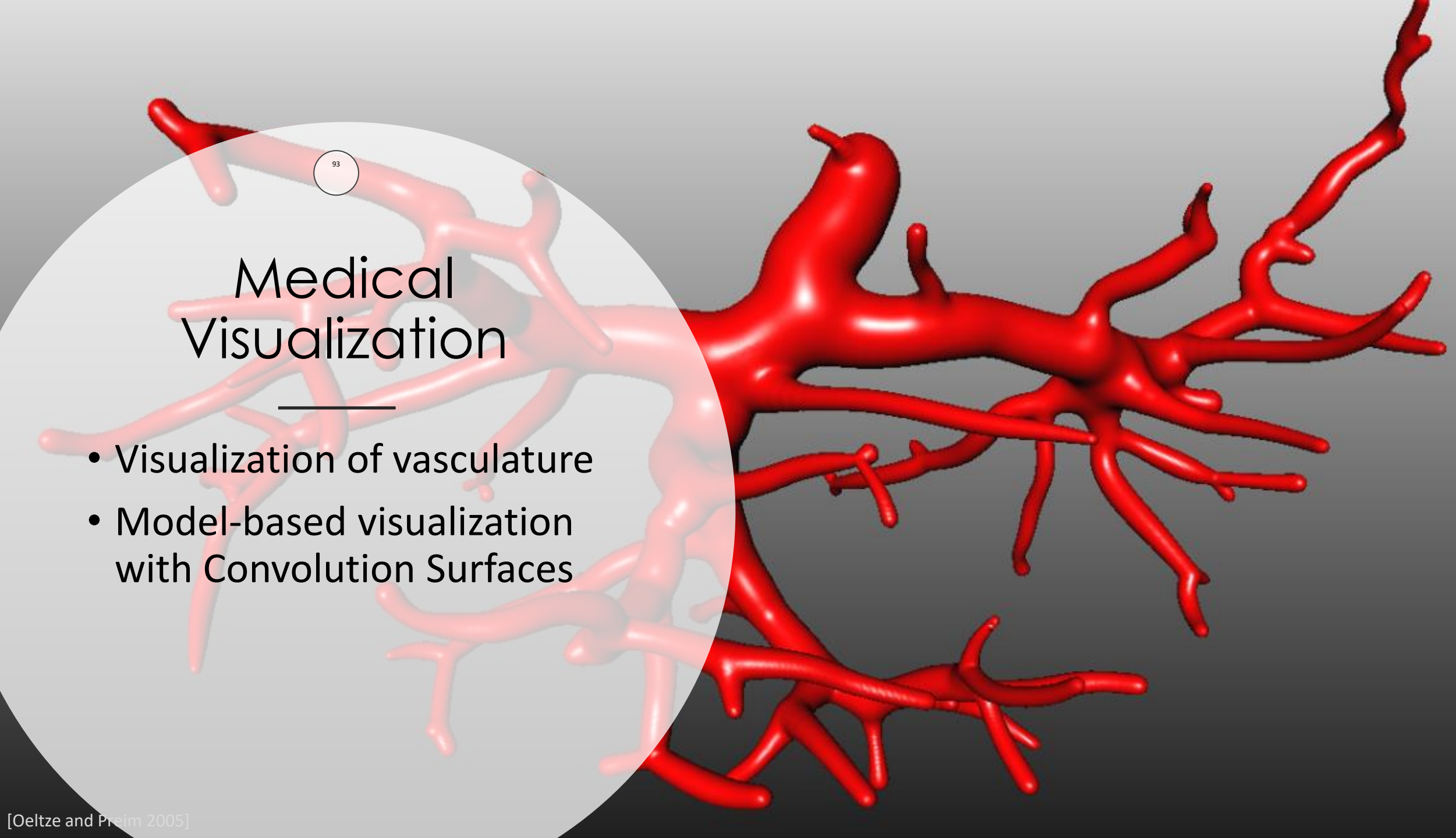
Interaction: select seed regions where stream tubes are started



[Schroeder et al. 1998]

Medical Visualization

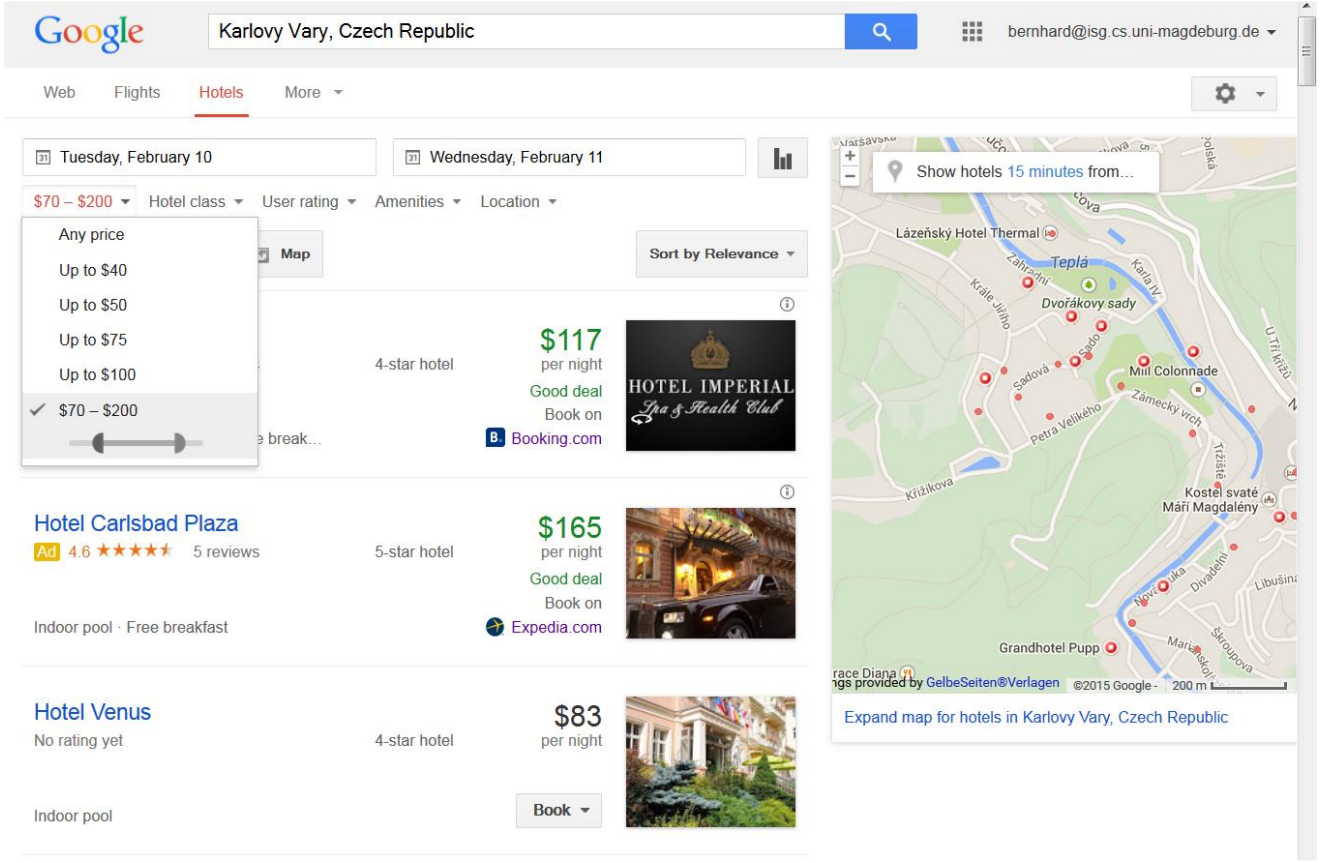
- Visualization of vasculature
- Model-based visualization with Convolution Surfaces



[Oeltze and Preim 2005]

Geospatial Data: Hotel Search

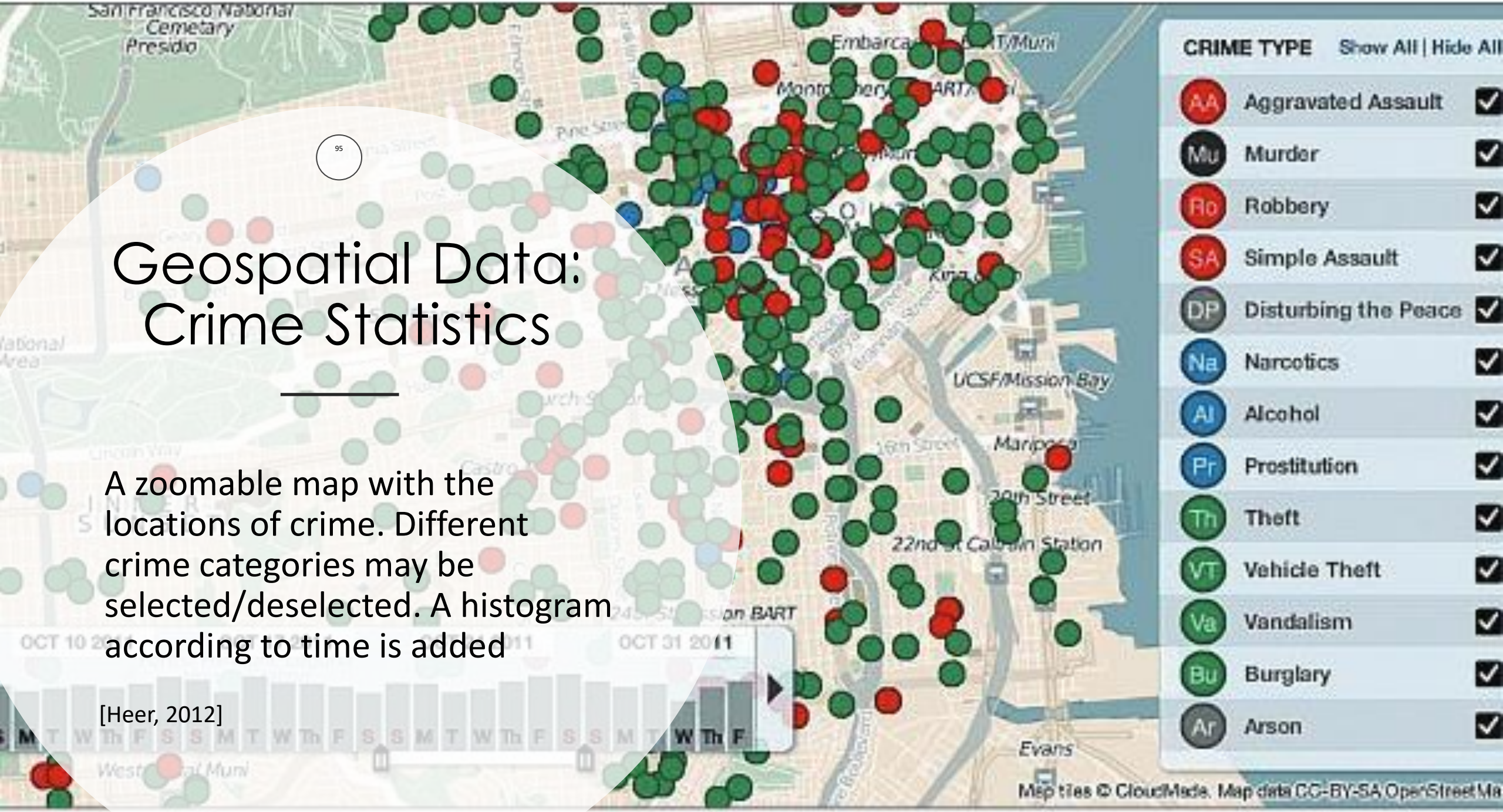
Dynamic query (price range), display of relevant hotels with links to further information. Map display is updated automatically.



Geospatial Data: Crime Statistics

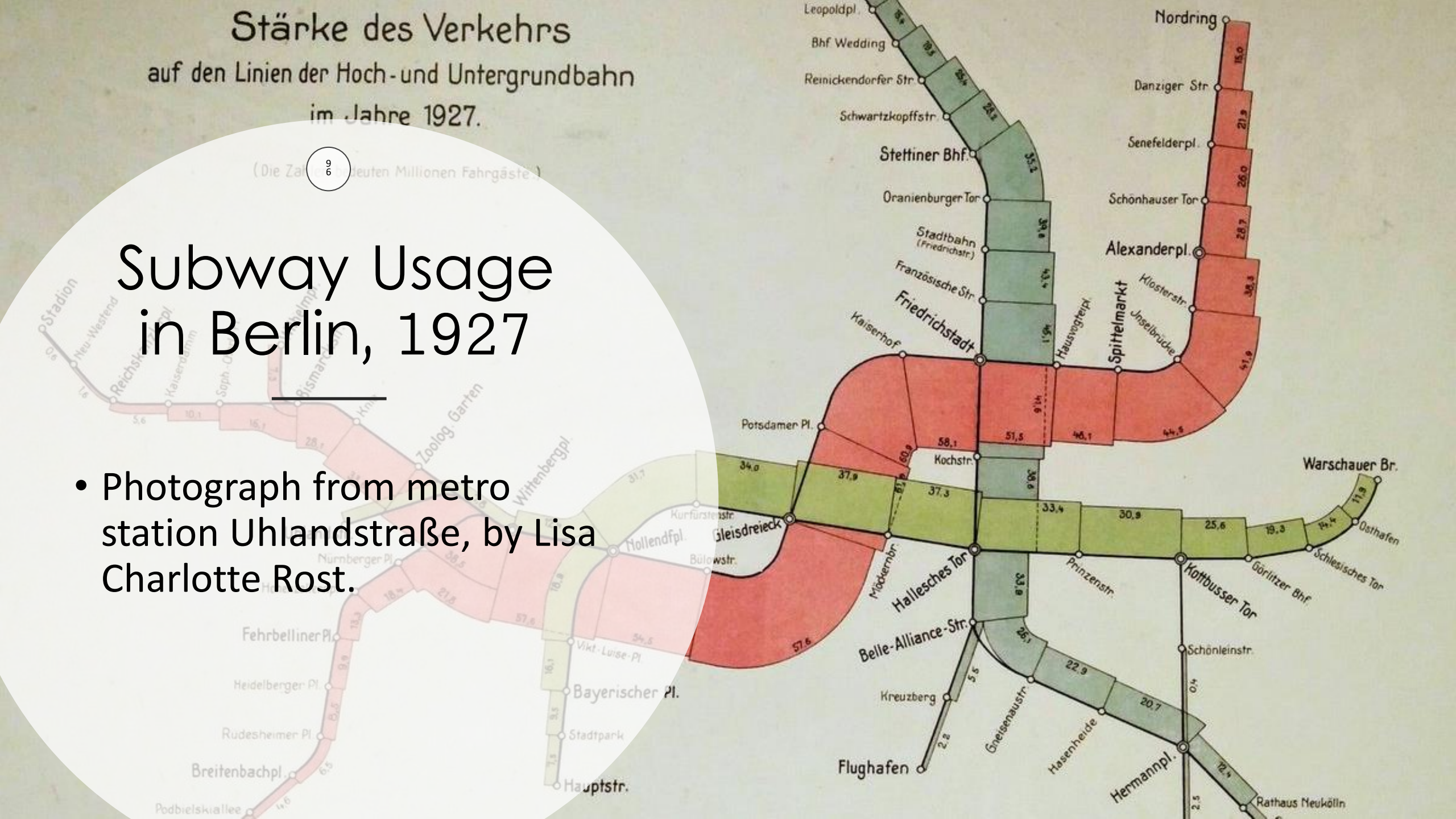
A zoomable map with the locations of crime. Different crime categories may be selected/deselected. A histogram according to time is added

[Heer, 2012]



Subway Usage in Berlin, 1927

- Photograph from metro station Uhlandstraße, by Lisa Charlotte Rost.



General Rules

- Choose an effective encoding for your data type (quantitative, ordinal, nominal) [Mackinlay86]
- Try to use pre-attentive features to support the most important tasks, e.g., differentiation of “normal” from critical
- Avoid combinations that inhibit preattentive recognition (most combinations require search)
- Provide legends
- Avoid eye-candy

What Have You Learned

- Details about marks and visual variables
- Brief introduction to the human visual system
- Perception of color and other visual encodings
- What are the two stages of visual perception

➔ What are the consequences for visualization

You should now be able to critique visualizations and make constructive improvement suggestions

Questions???