

CS-E4840

Information Visualization

Lecture 7: Human perception

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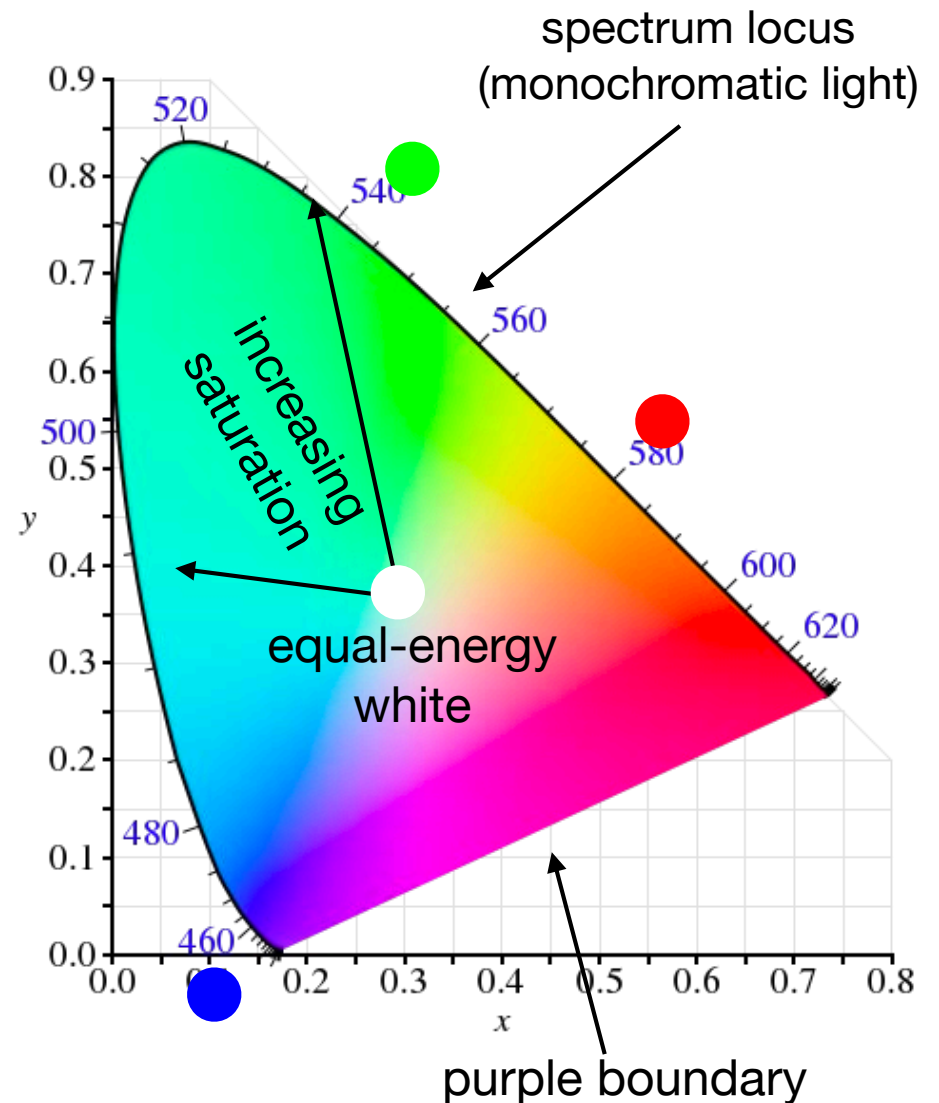
22 March 2021

Recap

Last lecture: Colour

CIE xyY model: chromaticity diagram

- Colour is 3-dimensional: luminance (Y, 1d) + **chromaticity (xy, 2d)**
- It can be used to present all visible colors as a combination of 3 primary colors at (x,y) coordinates (0,0), (0,1), (1,0).
- *Standard observer* is a hypothetical person whose colour sensitivity is held to be that of a typical person (measurements are from prior 1931)
- **Problem 1:** primary colors (xyY) are non-physical & no combination of 3 physical colours could present all perceivable colours
- **Problem 2:** colors are perceptually non-uniform

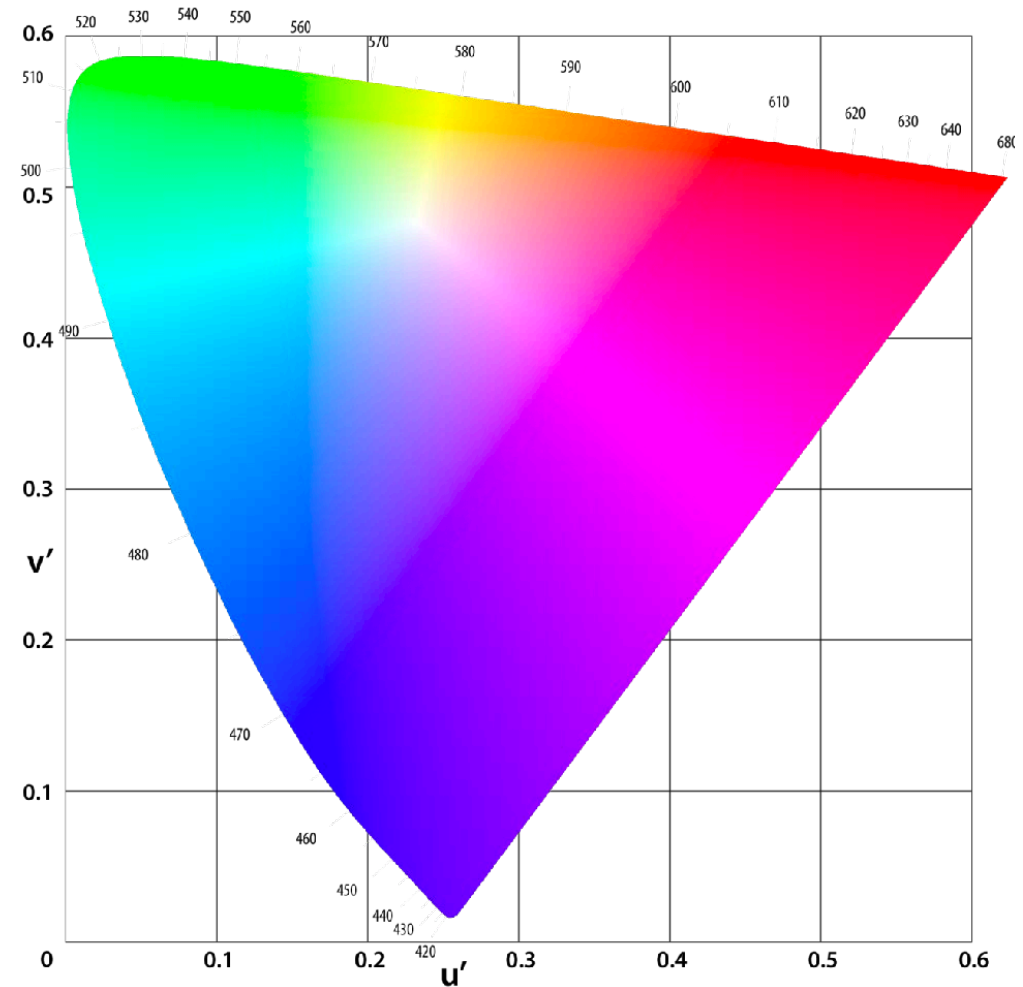


Perceptually more uniform CIELUV

- Derived from the CIE XYZ tristimulus model
 - CIE XYZ** reference white at (X_n, Y_n, Z_n)
 - CIE xyY** equations are
 - $x = X/(X+Y+Z)$
 - $y = Y/(X+Y+Z)$
 - CIELUV** equations are
 - $L^* = 116(Y/Y_n)^{1/3} - 16$
 - $u^* = 13L^*(u' - u'_n)$
 - $v^* = 13L^*(v' - v'_n)$
 - where $u' = 4X/(X+15Y+3Z)$ and $v' = 9Y/(X+15Y+3Z)$
- CIELUV** is perceptually more uniform, i.e., the perceptual difference of colours is about

$$\Delta E_{uv}^2 = \sqrt{(\Delta L^*)^2 + (\Delta u^*)^2 + (\Delta v^*)^2}$$

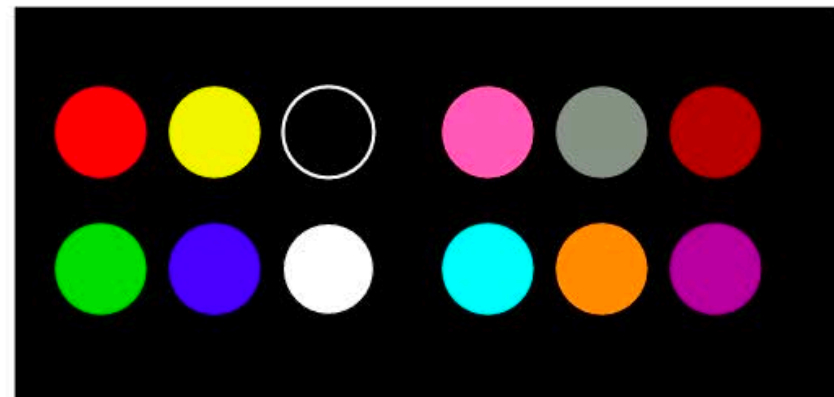
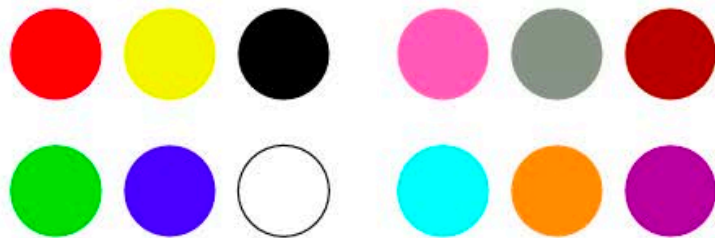
where 1 = approximately just noticeable difference



https://en.wikipedia.org/wiki/CIELUV#/media/File:CIE_1976_UCS.png

Colour for labelling

- For nominal data (e.g., coloured symbols represent companies from different sectors) ensure the following when choosing colours for labels:
 - distinctness
 - unique hues
 - contrast with background
 - colour blindness (avoid red-green distinctions)
 - number (5-10 colour scan be rapidly distinguished)
 - field size
 - convention (in west: red = danger, hot; green = good, go etc)



Colour for labelling: palettes

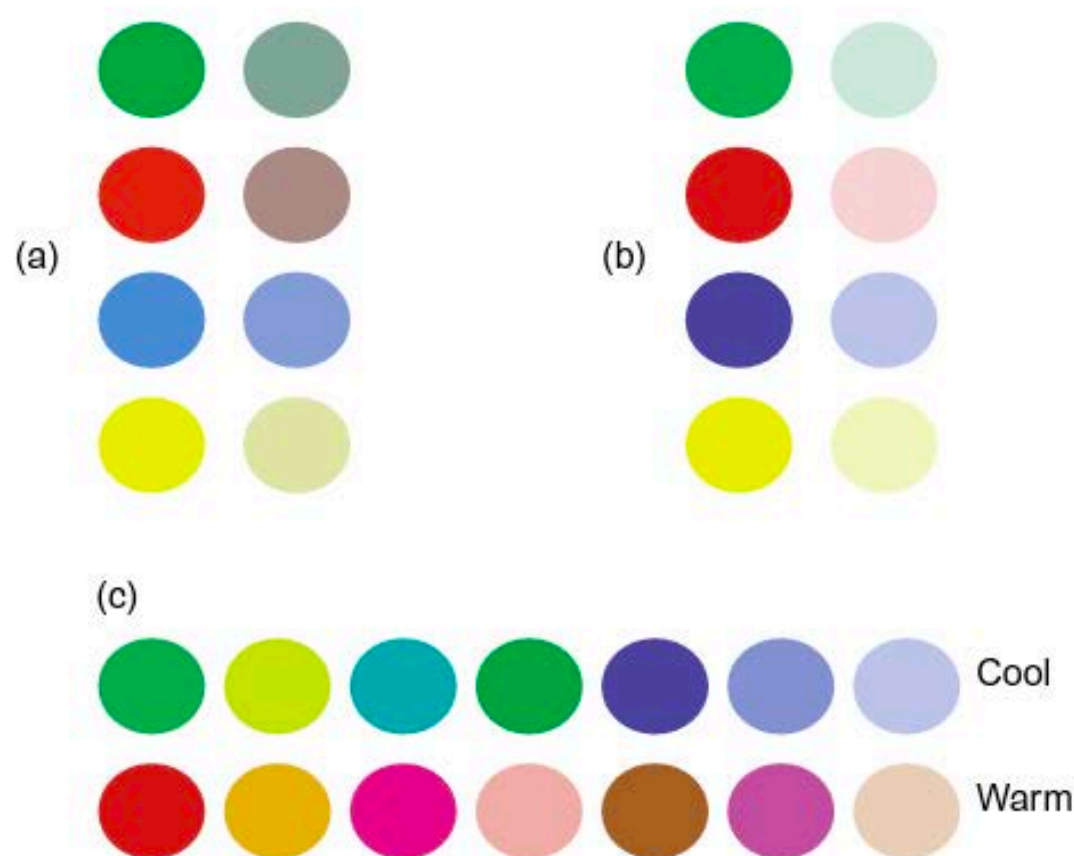


Figure 4.25 Families of colors. (a) Pairs related by hue; family members differ in saturation. (b) Pairs related by hue; family members differ in saturation and lightness. (c) A family of cool hues and a family of warm hues.

Colour for labelling: background

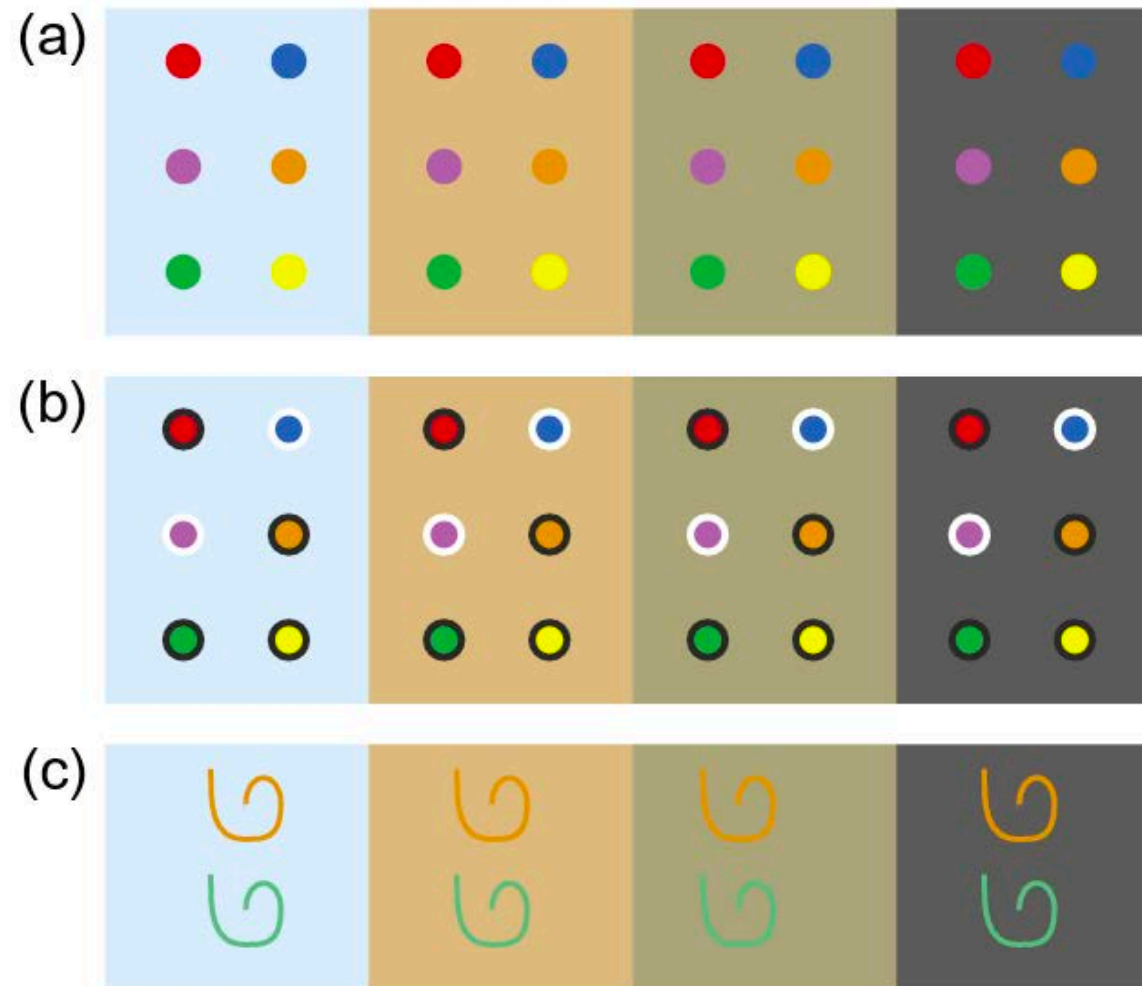


Figure 4.21 (a) Note that at least one member of the set of six symbols lacks distinctness against each background. (b) Adding a luminance contrast border ensures distinctness against all backgrounds. (c) Showing color-coded lines can be especially problematic.

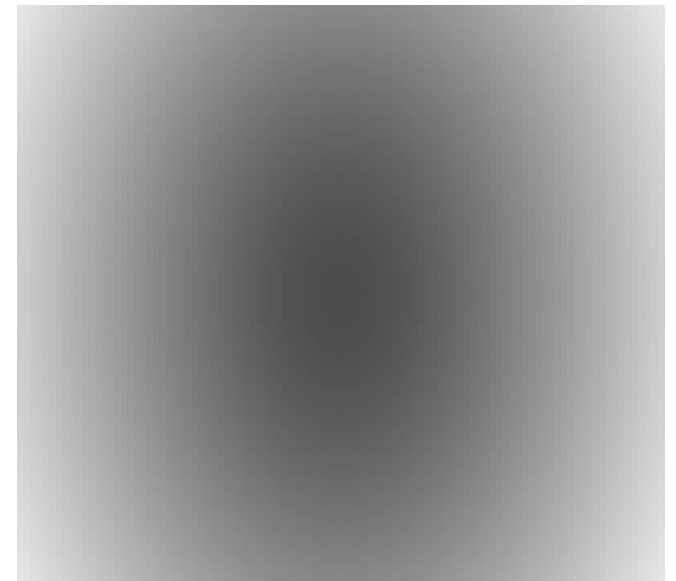
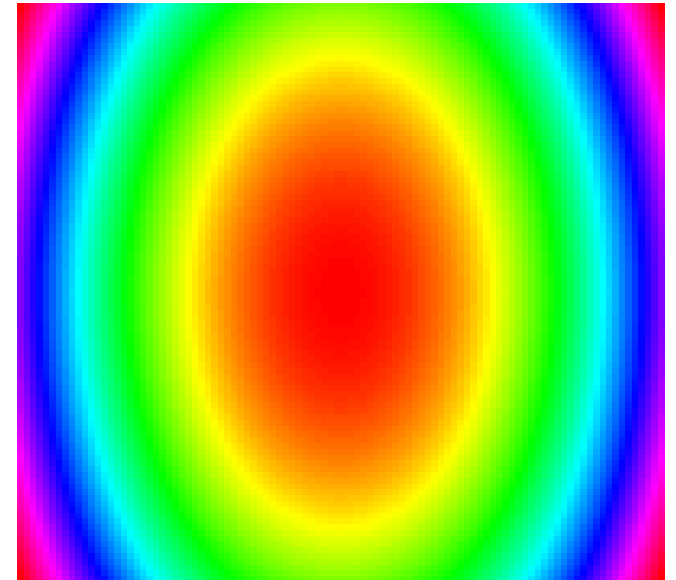
Colour scales

- Some differences are not perceived by colour blind (avoid red-green channel!)
- Perceptually **ordered channels** are in general formed from the six colour opponent channels. Other ordering include cold-hot, dark-light.
- **Level of detail:** luminance (e.g., grayscale) shows highest level of detail.
- **Perceptually constant steps:** Uniform colour spaces (e.g., CIELUV) can be used to construct scales with perceptually constant steps
- **Reading values from the scale:** minimise contrast effects by cycling through many colours
 - you can even follow a spiral in colour space
- **Misclassification of data:** colour category boundaries may cause misclassification of data

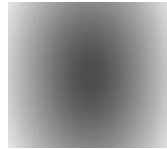
Colour scale examples

- **Spectrum (rainbow) scale**
 - perceptually very non-uniform and not ordered
 - can create “false contours”
 - good for reading back the values
 - should not be used if the shape of the data is important
- **Grayscale**
 - not good for reading back values
 - shows detail and shape of the data well

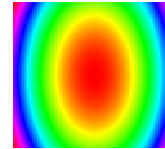
...but usually you should use something else...



Colour scales



grayscale



spectrum

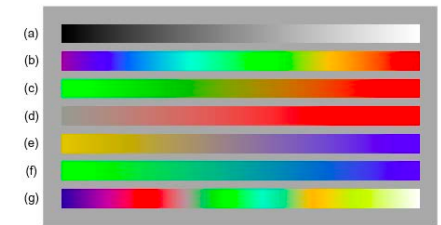


Figure 4.27 Seven different color sequences: (a) Grayscale. (b) Spectrum approximation. (c) Red-green. (d) Saturation. (e, f) Two sequences that will be perceived by people suffering from the most common forms of color blindness. (g) Sequence of colors in which each color is lighter than the previous one.

	grayscale	spectrum	
Shows detail	+++	---	?
Perceptually constant steps	++	---	?
Reading values from a scale	---	+	?
Show true shape	+++	---	?
Ordering is shown well	++	--	?
Good for labeling	---	++	?
Colour-blind safe	+++	-	?
Shows zero point	---	--	?
...	?	?	?

Colour scales

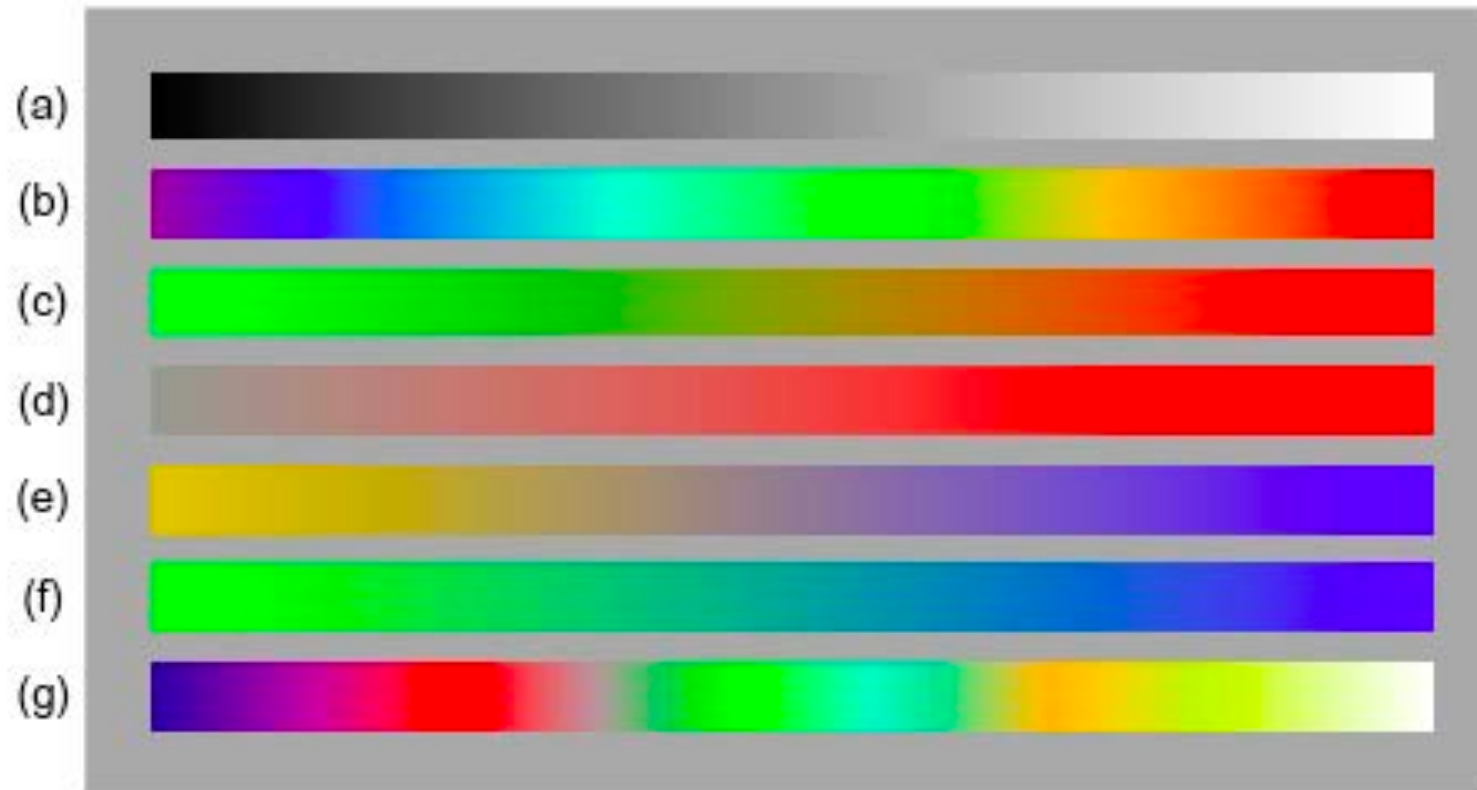
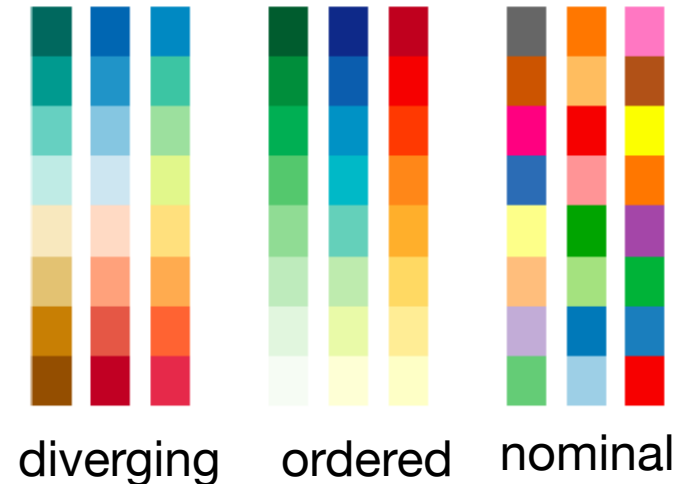


Figure 4.27 Seven different color sequences: (a) Grayscale. (b) Spectrum approximation. (c) Red–green. (d) Saturation. (e, f) Two sequences that will be perceived by people suffering from the most common forms of color blindness. (g) Sequence of colors in which each color is lighter than the previous one.

Colour scales

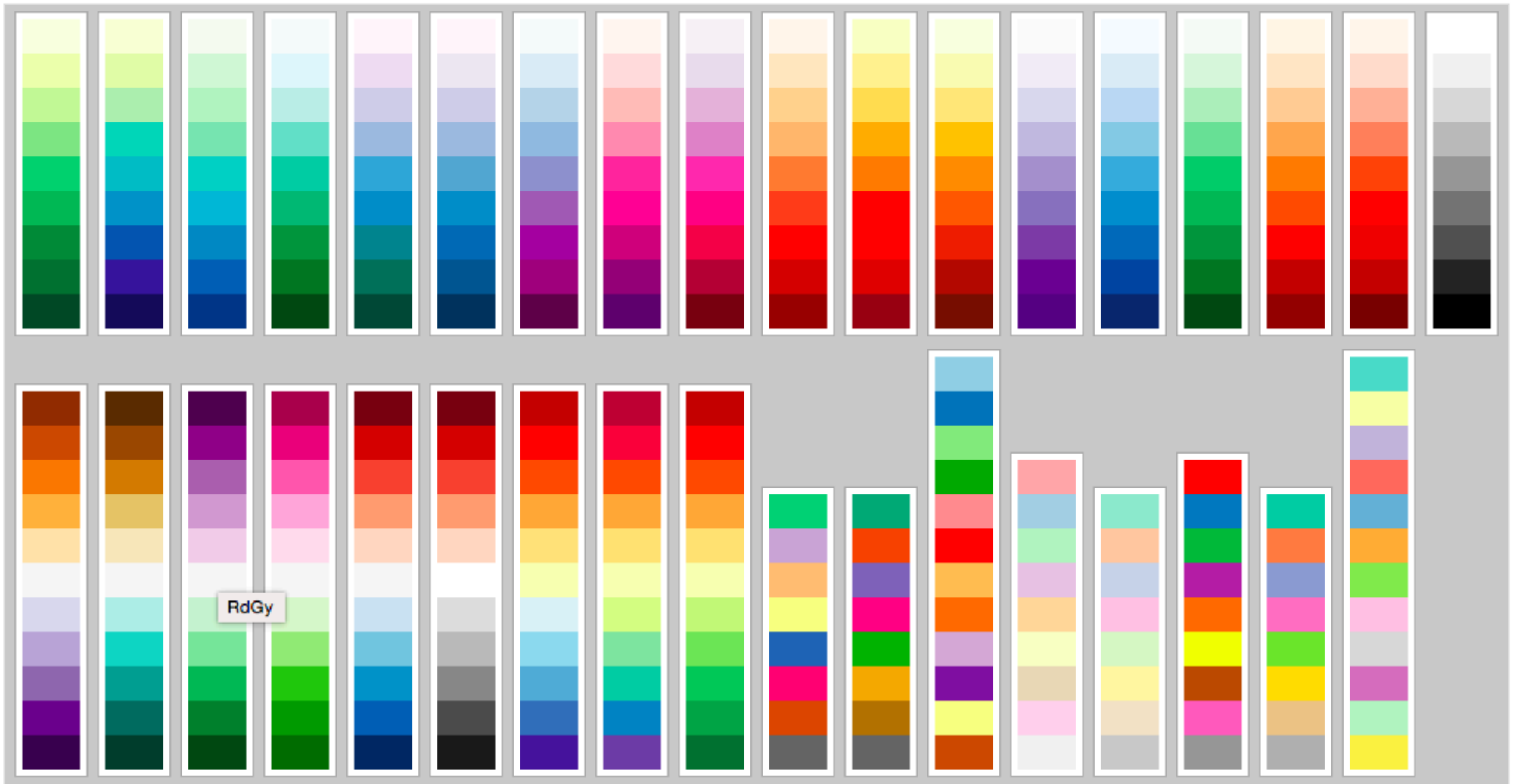
Some hints on selecting suitable colour scale:

- **Nominal** (values have no order):
 - Same as using colour for labelling. Colors should be as distinctive as possible.
- **Ordinal sequence** (values have order):
 - Colors should have perceptually the same ordering as the scale. Use luminance channel (if possible) as well as colors.
- **Ratio sequence** (values have order, there is a true zero and values can be negative)
 - Use diverging sequences: zero has neutral colour (gray or white). Opposite ends use opponent colors.
- **Interval sequence** (difference between two values is what matters)
 - Colors changes should perceptually reflect the differences in the data. The scale should be based on a uniform colour space, or clearly defined (discretised) colour steps should be used. Adding a contour map is a good option here.
- **Reading the actual value from data is important:**
 - Difficult task due to contrast issues. Consider cycling through many colors. Use luminance channel to indicate order.



Colour scales

RColorBrewer colour scales



Colour scales

The screenshot displays the ColorBrewer 2.0 web application interface. At the top, the title "COLORBREWER 2.0" is prominently displayed with the subtitle "color advice for cartography". Below the title, there are navigation links: "how to use", "updates", "downloads", and "credits".

The main interface is divided into several sections:

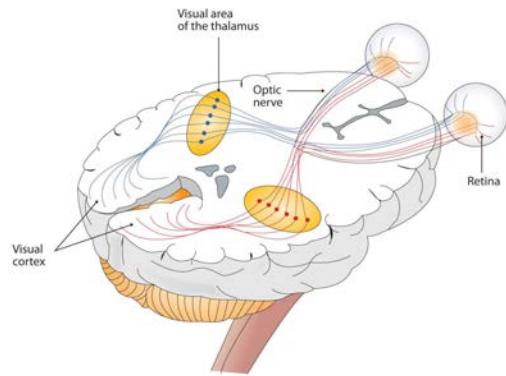
- Number of data classes:** Set to 3.
- Nature of your data:** Radio buttons for "sequential" (selected), "diverging", and "qualitative".
- Pick a color scheme:** Two columns of color swatches labeled "Multi-hue" and "Single hue".
- Only show:** Checkboxes for "colorblind safe", "print friendly", and "photocopy safe".
- Context:** Checkboxes for "roads", "cities", and "borders" (checked).
- Background:** Radio buttons for "solid color" (selected) and "terrain".
- Color transparency:** A slider control.
- 3-class BuGn:** A legend showing three color swatches with their corresponding HEX codes: #e5f5f9, #99d8c9, and #2ca25f.
- EXPORT:** A button to export the map.

The central part of the interface shows a map of the United Kingdom, where the administrative boundaries are colored according to the selected 3-class sequential scheme, ranging from light blue to dark green.

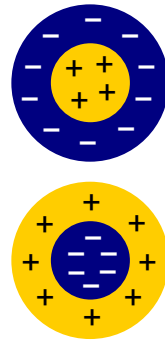
At the bottom left, the copyright notice reads: "© Cynthia Brewer, Mark Harrower and The Pennsylvania State University". Below this, there are links for "Support", "Back to Flash version", and "Back to ColorBrewer 1.0". At the bottom right, the "axismaps" logo is visible.

Harrower,
Brewer. ColorBrewer.
org: An Online Tool
for Selecting Colour
Schemes for
Maps, The
Cartographic
Journal, 40:1, 27-37,
2003. [https://doi.org/
10.1179/000870403
235002042](https://doi.org/10.1179/000870403235002042)

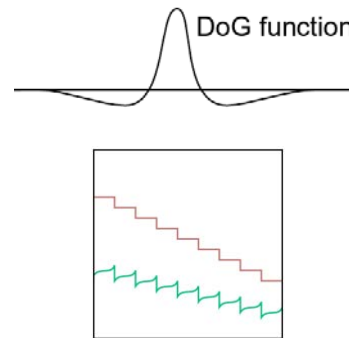
from retina to brain



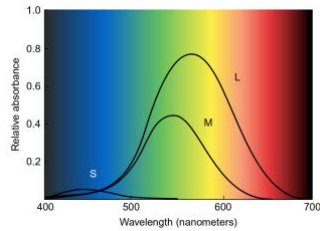
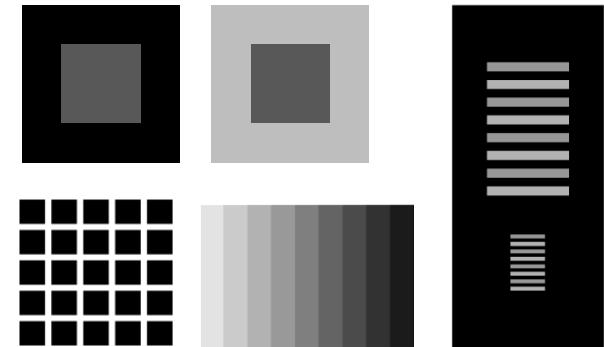
receptive field



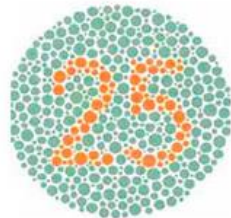
Difference of Gaussians



contrast illusions and crispening



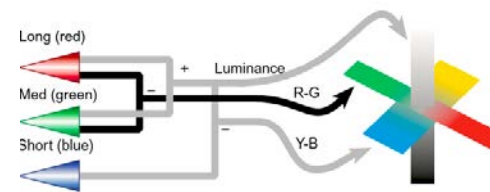
Trichromacy theory



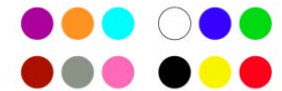
colour blindness



colour spaces



opponent colour theory



colour for labels, scales,
multidimensional data,
reproduction

Visual salience and finding information

(Ware Ch 5)

You can guide your attention to a degree

Read every other word, starting from the 1st or 2nd word:

Visual Human search perception is plays a an type important of role
perceptual in task the requiring area attention of that visualization. typically
An involves understanding an of active perception scan can of significantly
the improve visual both environment ...

*From https://en.wikipedia.org/wiki/Visual_search &
<https://www.csc2.ncsu.edu/faculty/healey/PP/>*

You can guide your attention to a higher degree

Read every other word, starting from the 1st or **2nd** word:

Visual **Human** search **perception** is **plays** a **an** type **important** of **role** perceptual **in** task **the** requiring **area** attention **of** that **visualization**. typically **An** involves **understanding** an **of** active **perception** scan **can** of **significantly** the **improve** visual **both** environment ...

- The role of **visual attention**, **query**, and **search**:
 - You can guide your **attention** to black (**red**) text
 - At the same time, you can *ignore* **red** (black) text
 - Two step process:
 - **visual query**: read the black (not red) text
 - **visual search**: carry out search to find patterns to resolve the query

From https://en.wikipedia.org/wiki/Visual_search &
<https://www.csc2.ncsu.edu/faculty/healey/PP/>

Query: how many 3s?

455865876864565749286555584765298742309847249473247
324879427149572389742982479280742938742564875647654
902842968476745464274784674573847648562484789847985

455865876864565749286555584765298742**3**0984724947**3**247
324879427149572**3**897429824792807429**3**8742564875647654
90284296847674546427478467457**3**847648562484789847985

Sometimes it is difficult for you to guide your attention



Reading this text might be difficult because of the famous Finnish politician stealing your attention. Motion and especially *appearance* of a new object attracts attention. Human faces seem to be especially effective. This seems right and makes ecological sense. When early man was outside a cave, awareness of emerging objects in the periphery would have had clear survival value. Such movement may have signalled immediate and deadly danger.



A model for perceptual processing

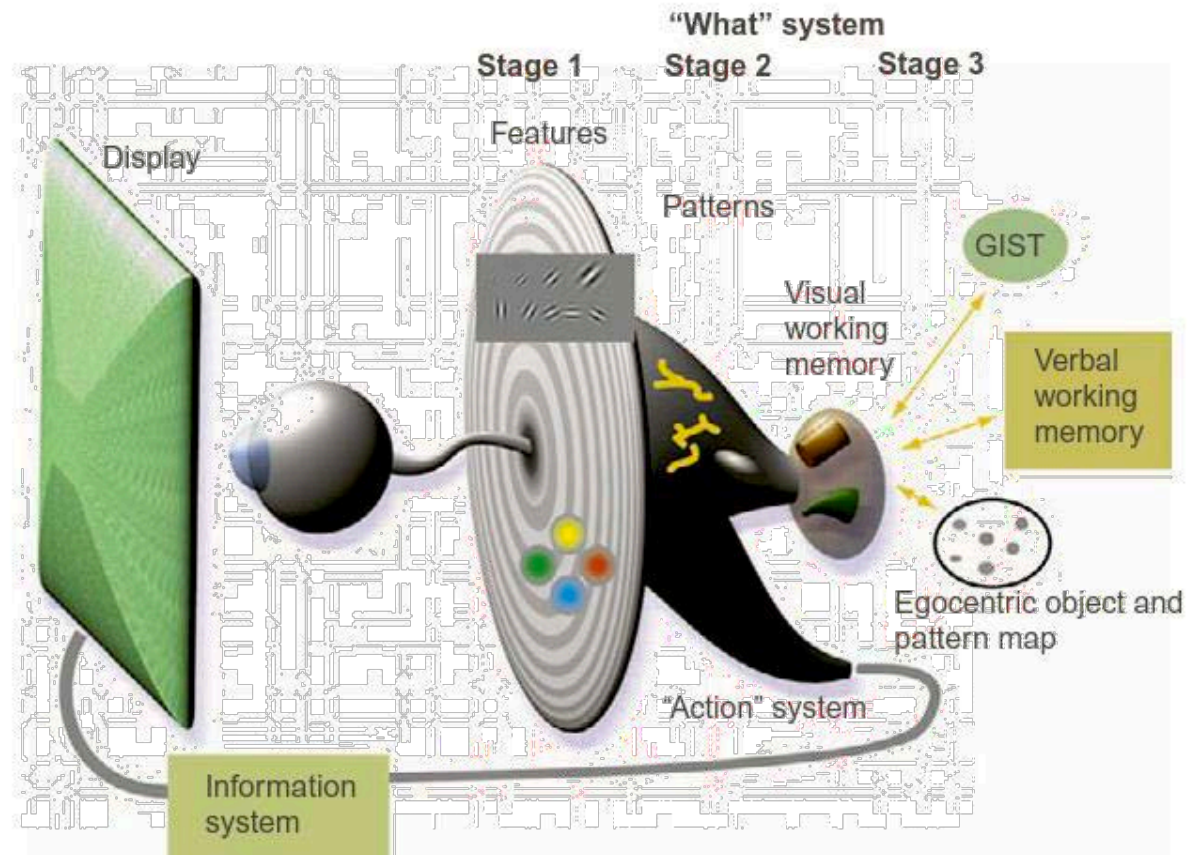
1. Parallel processing to extract low-level properties of the visual scene

- rapid parallel processing
- extraction of features, orientation, colour, texture and movement patterns
- iconic store
- bottom-up, data driven processing

2. Pattern perception

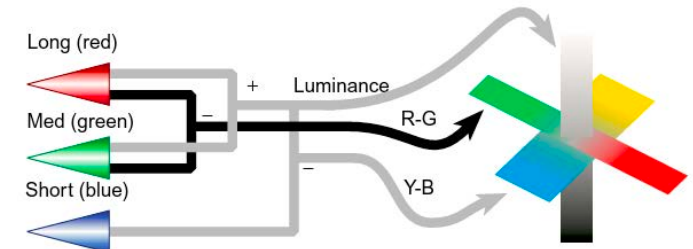
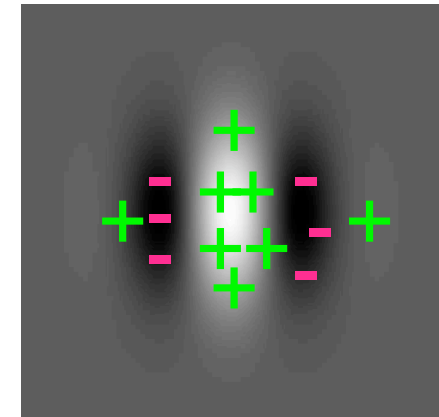
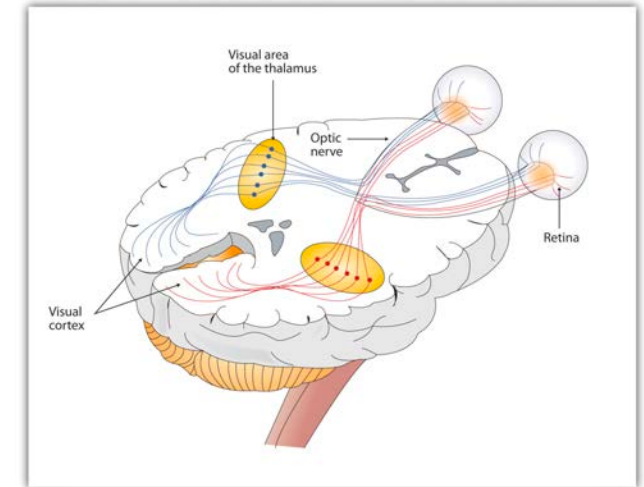
- slow serial processing
- involves both working memory and long-term memory
- arbitrary symbols relevant
- different pathways for object recognition and visually guided motion

3. Visual working memory



Visual cortex

- V1 (primary visual cortex) and V2 (secondary visual cortex) of the visual cortex together make up to 40% of vision processing
- V1 and V2 are tuned to these properties
 - Elements of **form**
 - orientation and size (with luminance)
 - via the Gabor processor (explained later)
 - **Colour** (two types of signals)
 - via the opponent colour processing
 - Elements of local **stereoscopic depth**
 - Elements of local **motion**



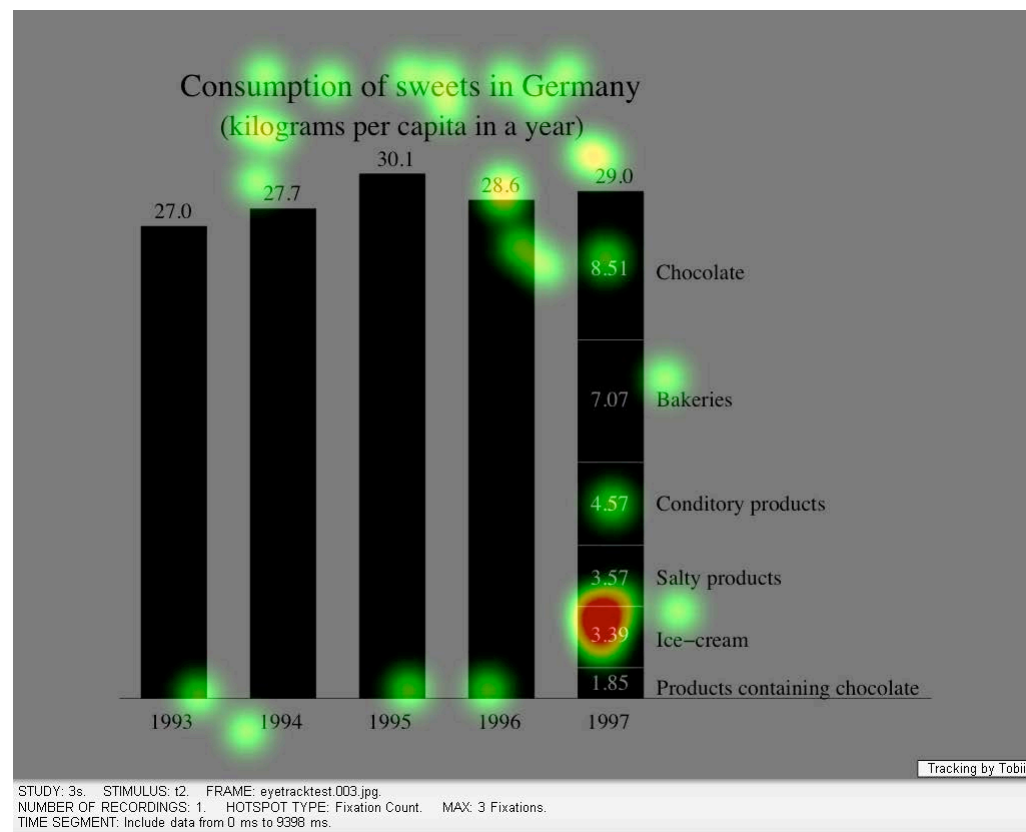
Visual channels

- The previous properties are processed separately, in parallel on different channels,
 - colour, form (orientation and size), motion
- Information expressed in one channel (e.g., colour of a symbol) does not interfere (much) with the information expressed in another channel (e.g., orientation of a symbol), and properties on different channels (e.g., colour and orientation) are visually distinct
- Different visual channels should be used to display aspects of data

Eye movements

- The eye moves according to three basic strategies:
 - **Saccadic movements.** Eye movements consist of **fixations** (duration 0.2-0.6 s), during which eye is relatively stable. Eye moves from fixation to fixation with saccades (duration 0.02-0.1 s, velocities up to $900^\circ/\text{s}$). Saccadic movements are pre-programmed (ballistic). We are practically blind during the saccade (saccadic suppression). Refocusing (accommodation) takes about 0.2 s.
 - **Smooth-pursuit movements.** We can track smoothly moving visual objects (and static objects while moving ourselves)
 - **Convergent movements.** When objects move closer or further away, our eyes converge or diverge.
- During this lecture we only consider saccadic movements and make (over?)simplification: information comes into visual system as a series of discrete snapshots.

Where did they look?



The heatmap shows the time spent at looking (fixations) at different parts of an image.

What do we really see?

- Higher frequency components off-visual axis are blurred (foveation)
- The foveated video (right) is what the test subject really saw (keep your gaze fixed to the center, you do not need to move your eyes)

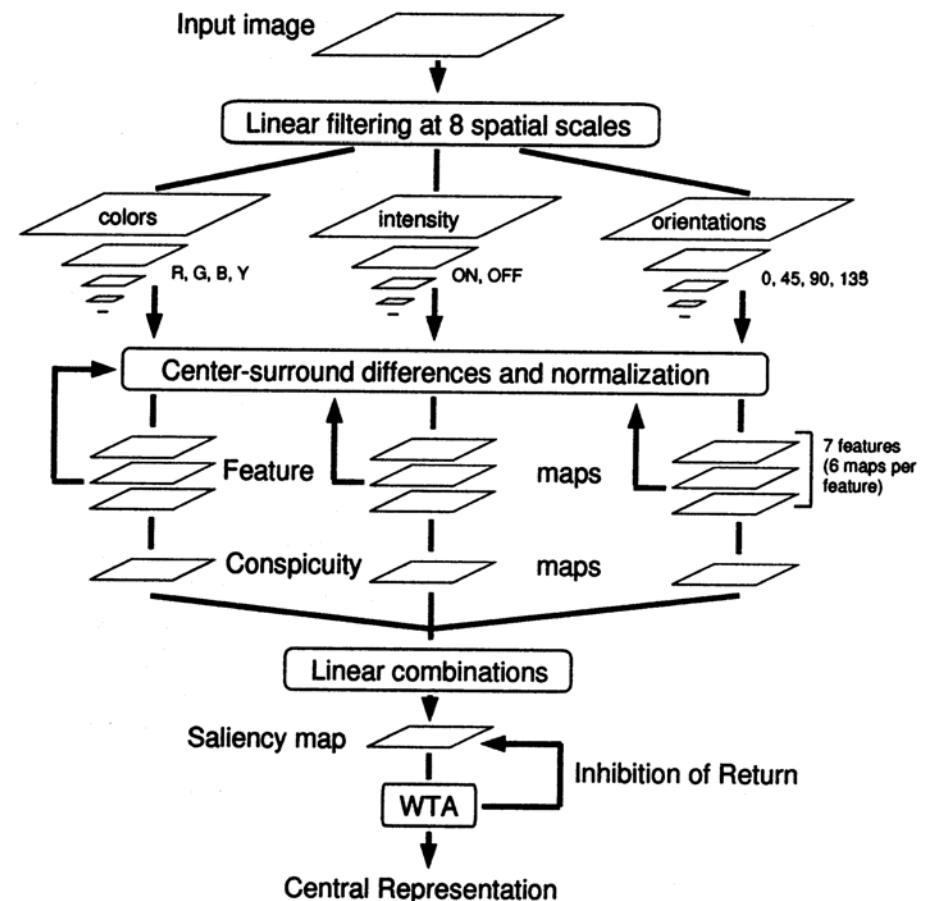


Guiding gaze

- **Bottom-up: salient features**
- Top-down: attention

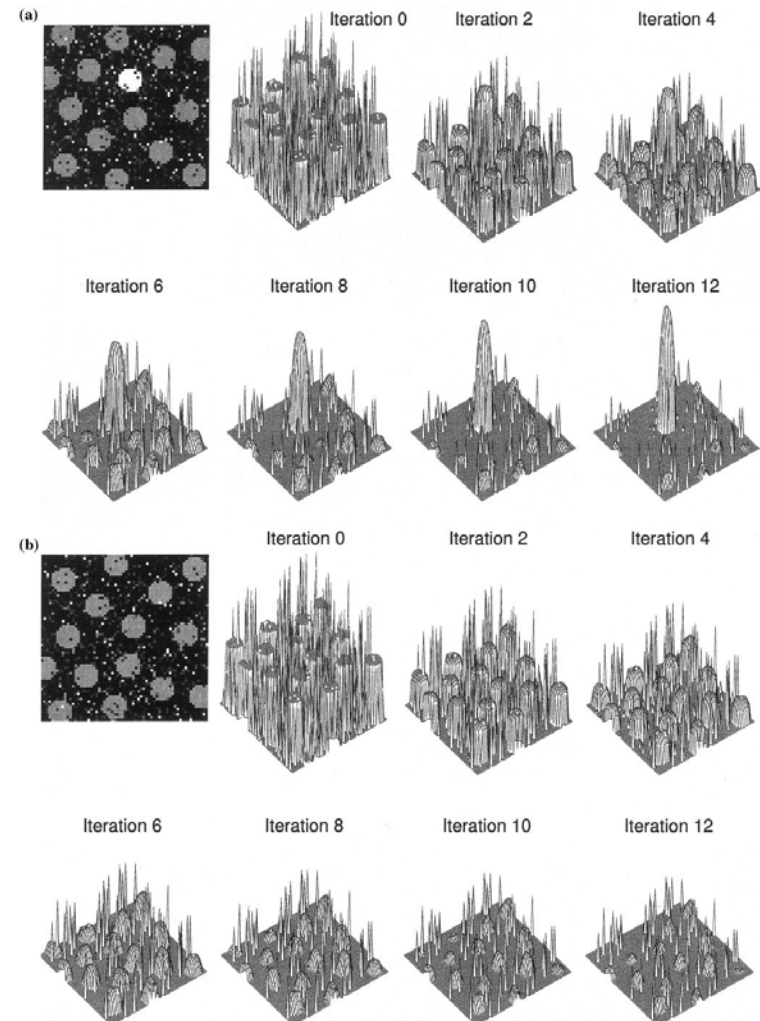
Computational model for visual attention: saliency map

- Loosely based on Treisman's feature integration theory
- First, low-level visual features are extracted (color channels, orientation, brightness), preprocessed with difference of Gaussians (DOG) models (**winner-take-all-training, resulting to sparse distribution of winners, or peaks, on the maps**), presented on 42 separate maps
- The maps are summed linearly, to form the saliency map
- The gaze is then directed to the point of maximum saliency
- In the case of static images, saliency of the viewed parts is suppressed



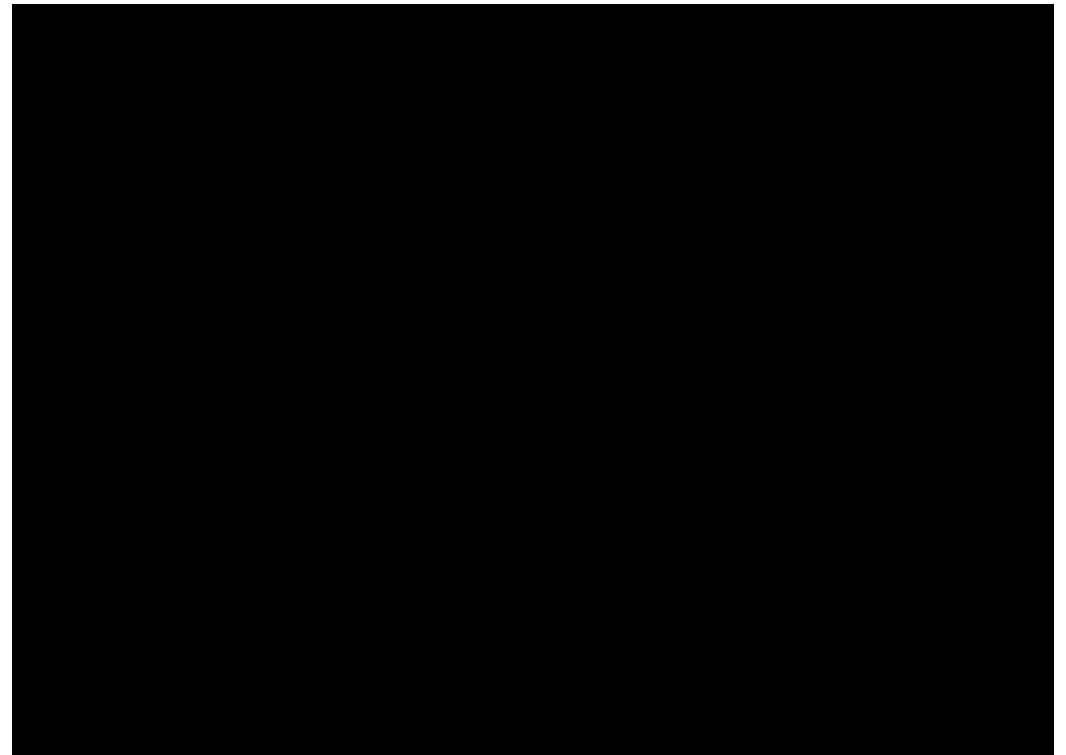
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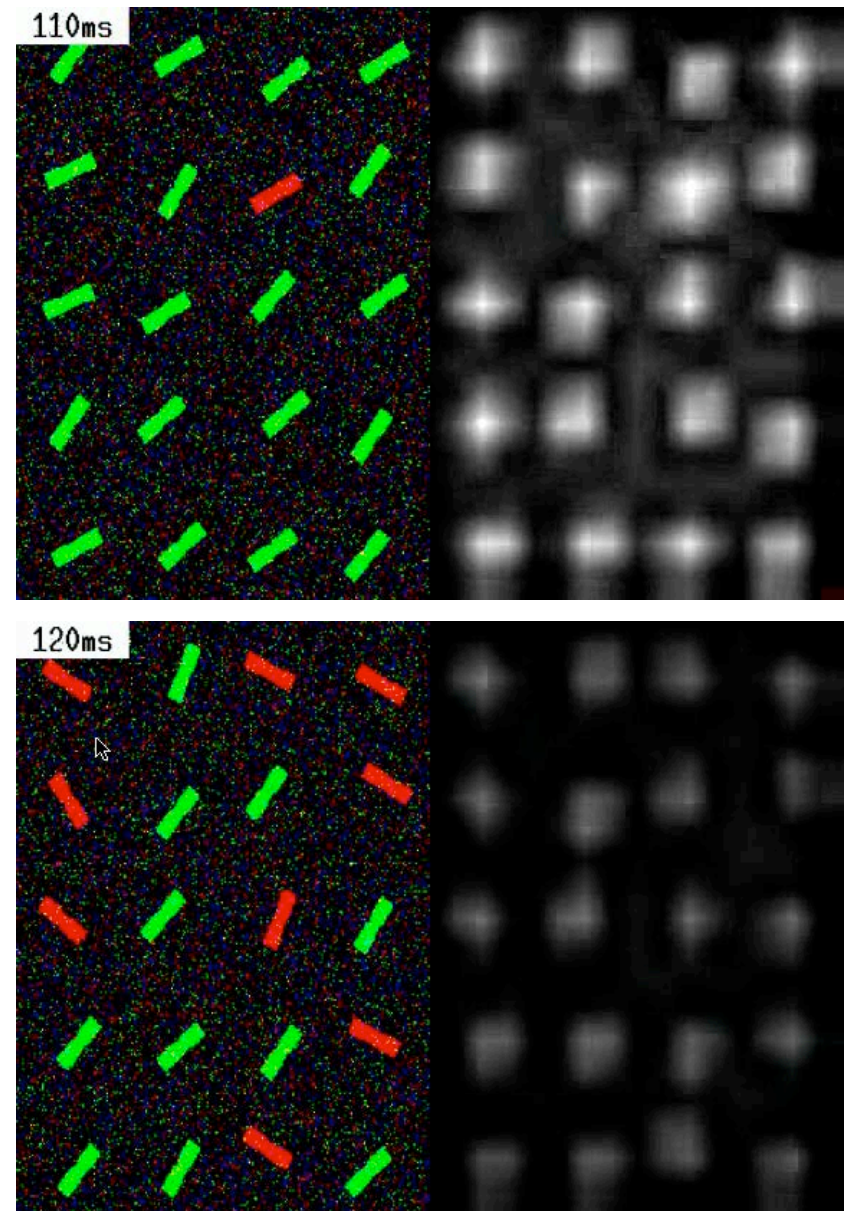
Computational model for bottom-up visual attention: saliency map

- Loosely based on Treisman's feature integration theory
- First, low-level visual features are extracted (color channels, orientation, brightness), preprocessed with difference of Gaussians (DOG) models (**winner-take-all-training, resulting to sparse distribution of winners, or peaks, on the maps**), presented on 42 separate maps
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- The gaze is then directed to the point of maximum saliency
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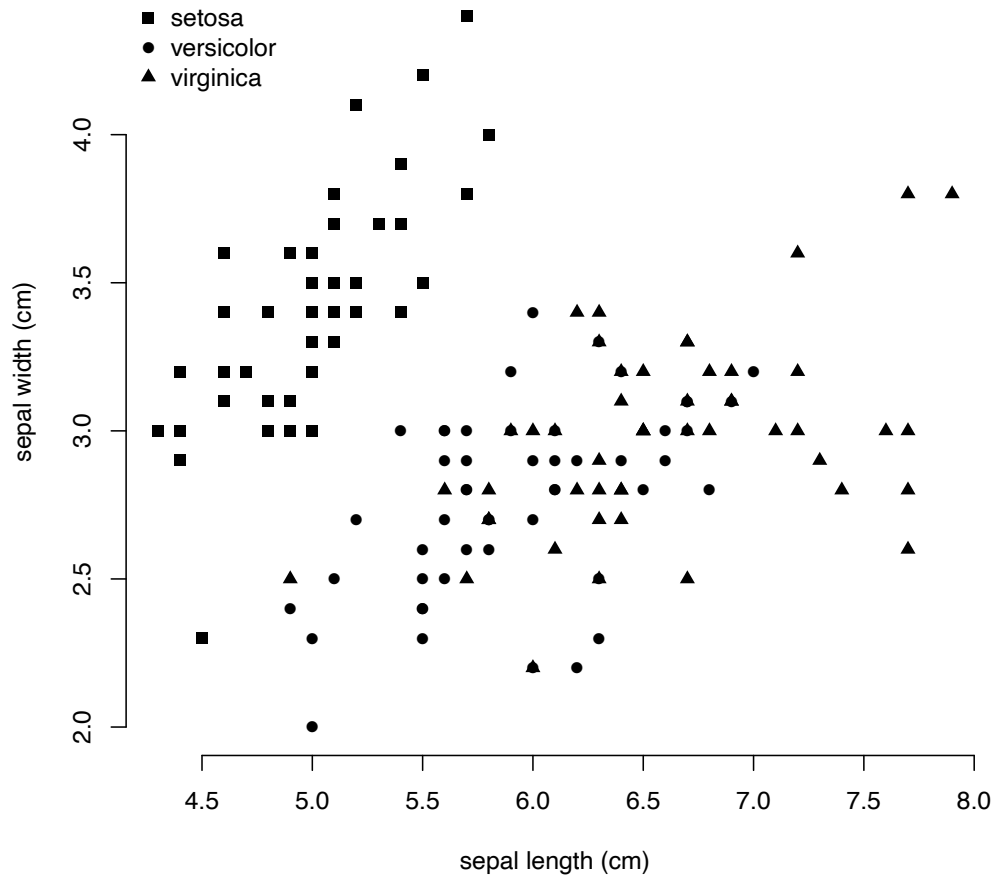


Some of the pre-attentive pop-up explained

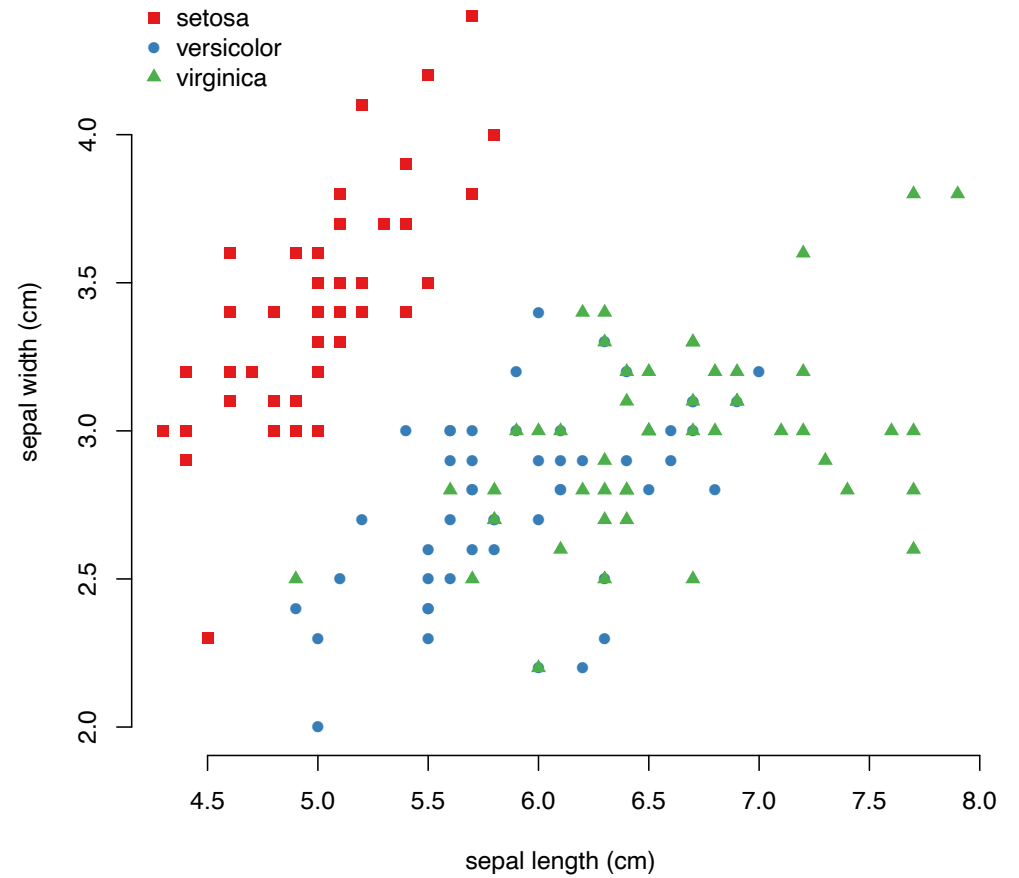
- The model reproduces some of the pre-attentive pop-out phenomena (Itti, Koch 2000)
- Search-time of pop-out task is independent of the number of distractors (pre-attentive search)
- Search-time of conjunction task increases linearly with the number of distractors (conjunction searches are usually non-pre-attentive). (Why?)



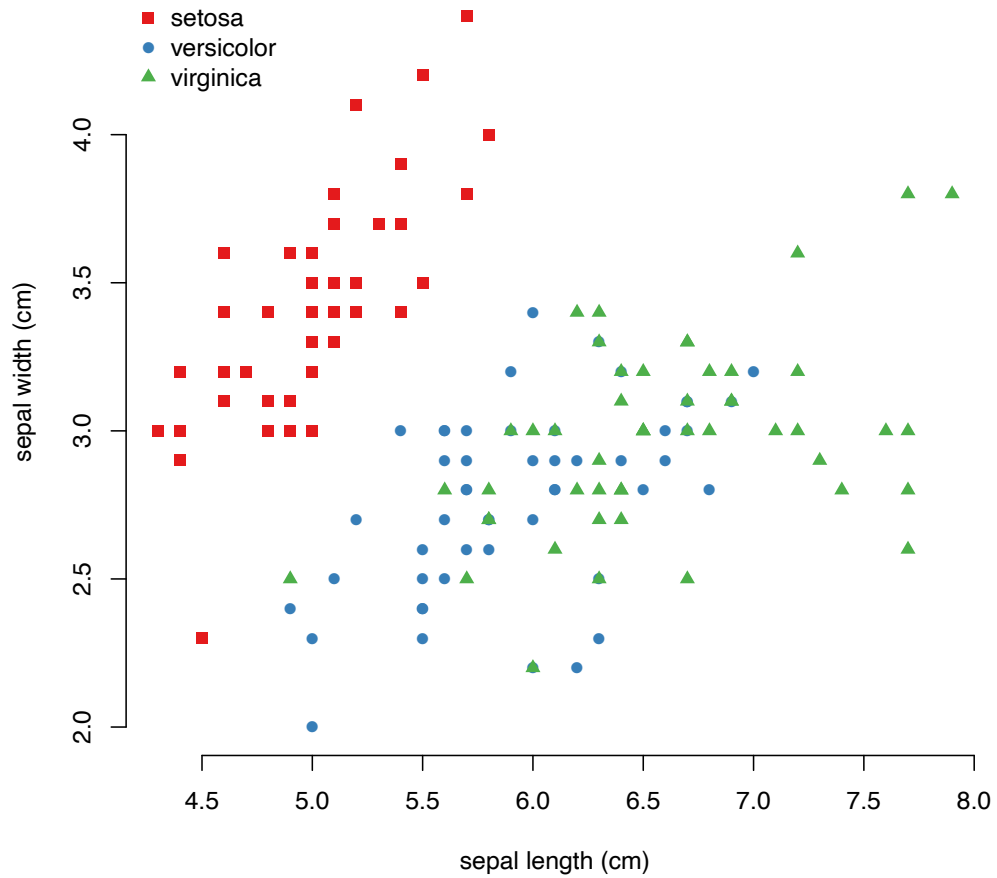
Saliency map on the right.



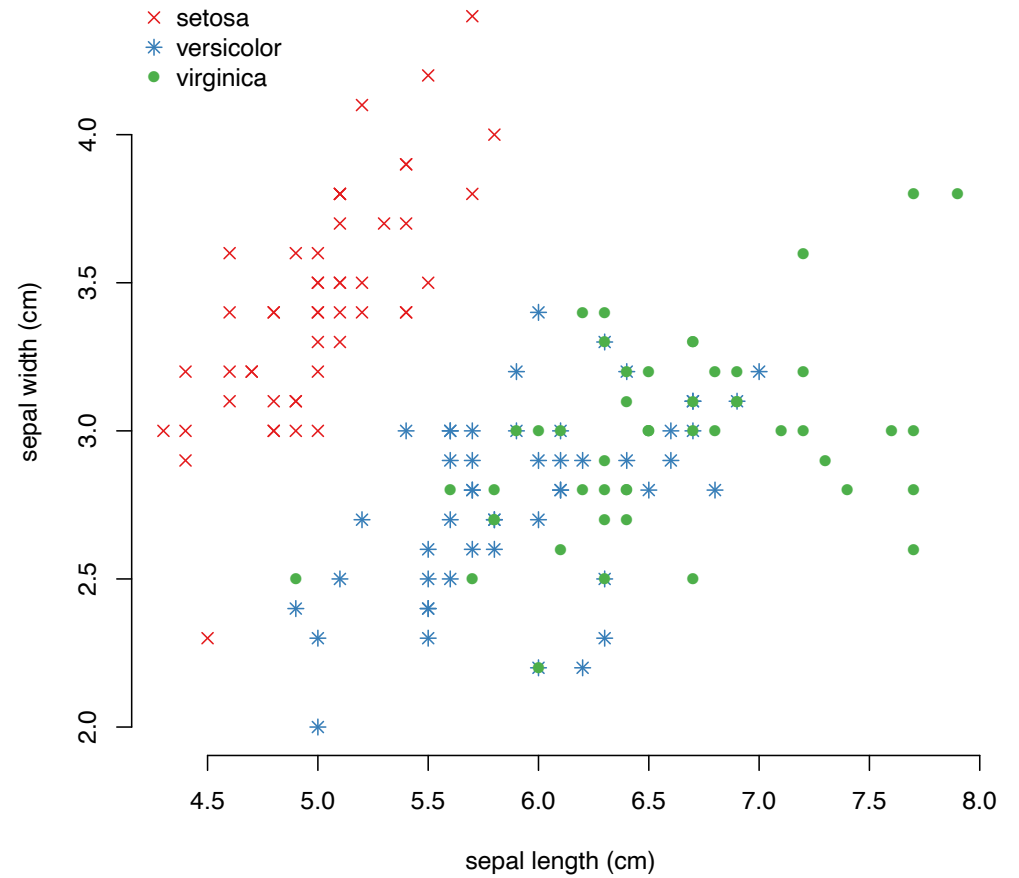
shape



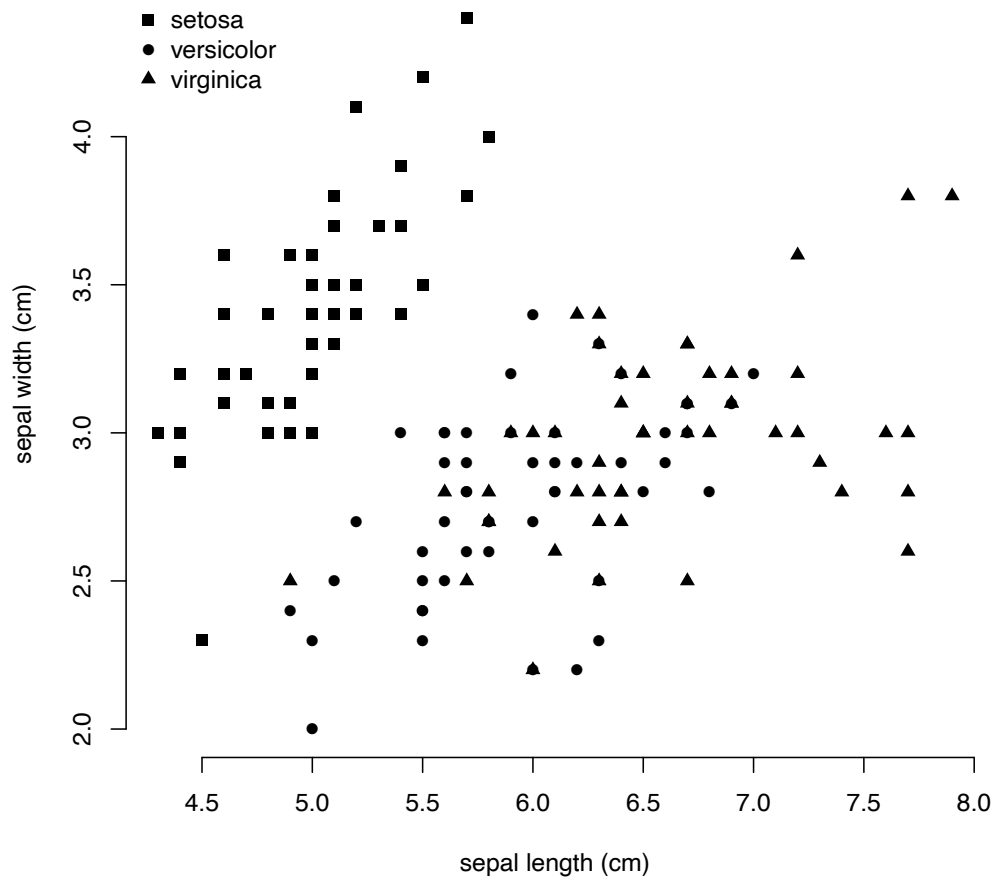
shape + colour



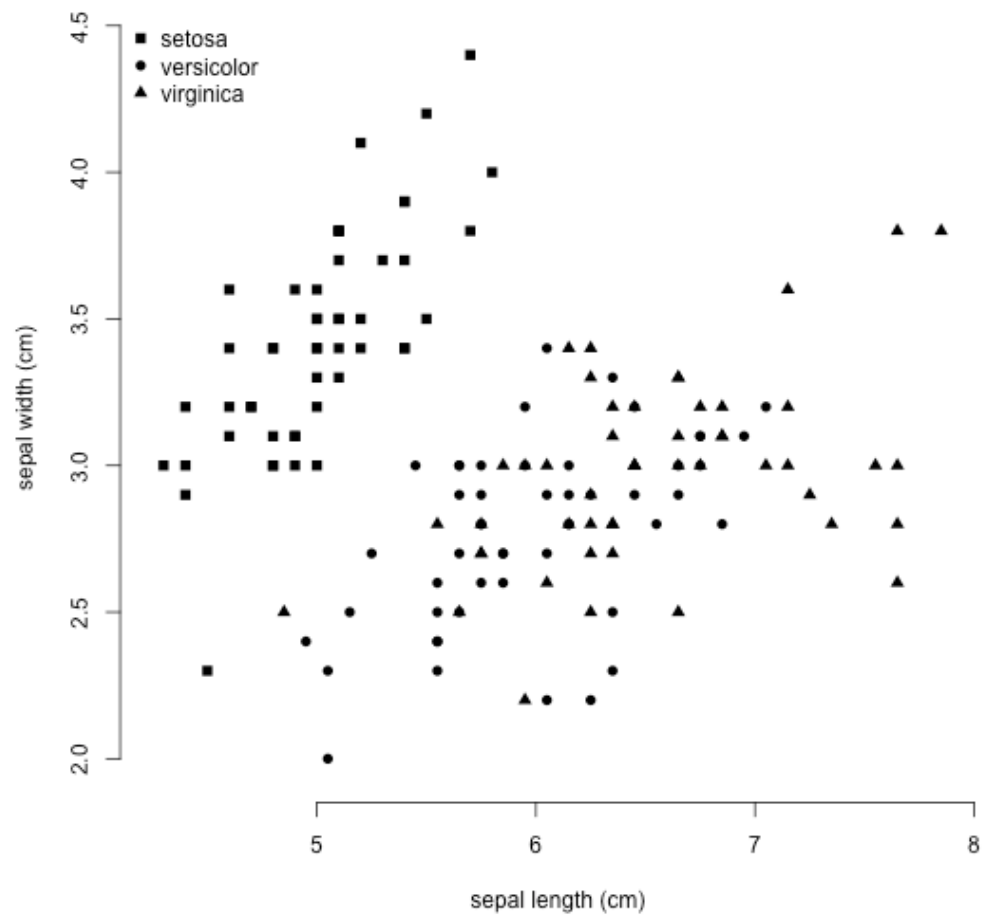
shape + colour



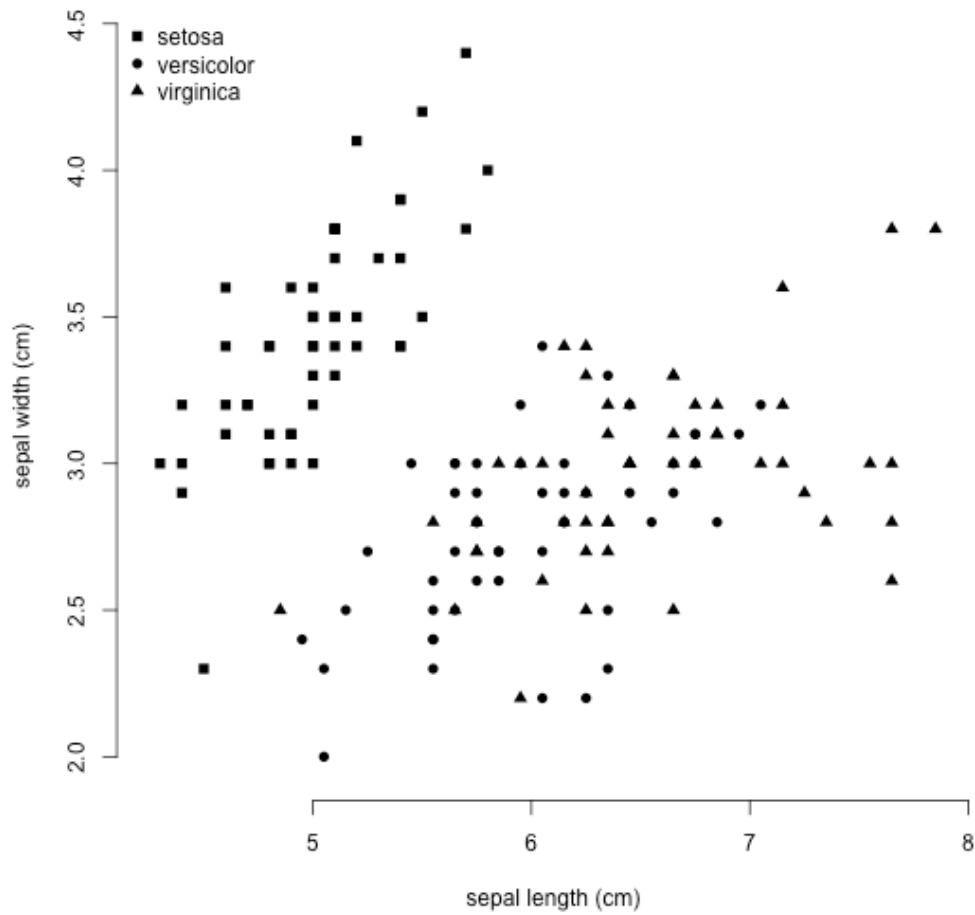
shape + orientation + colour



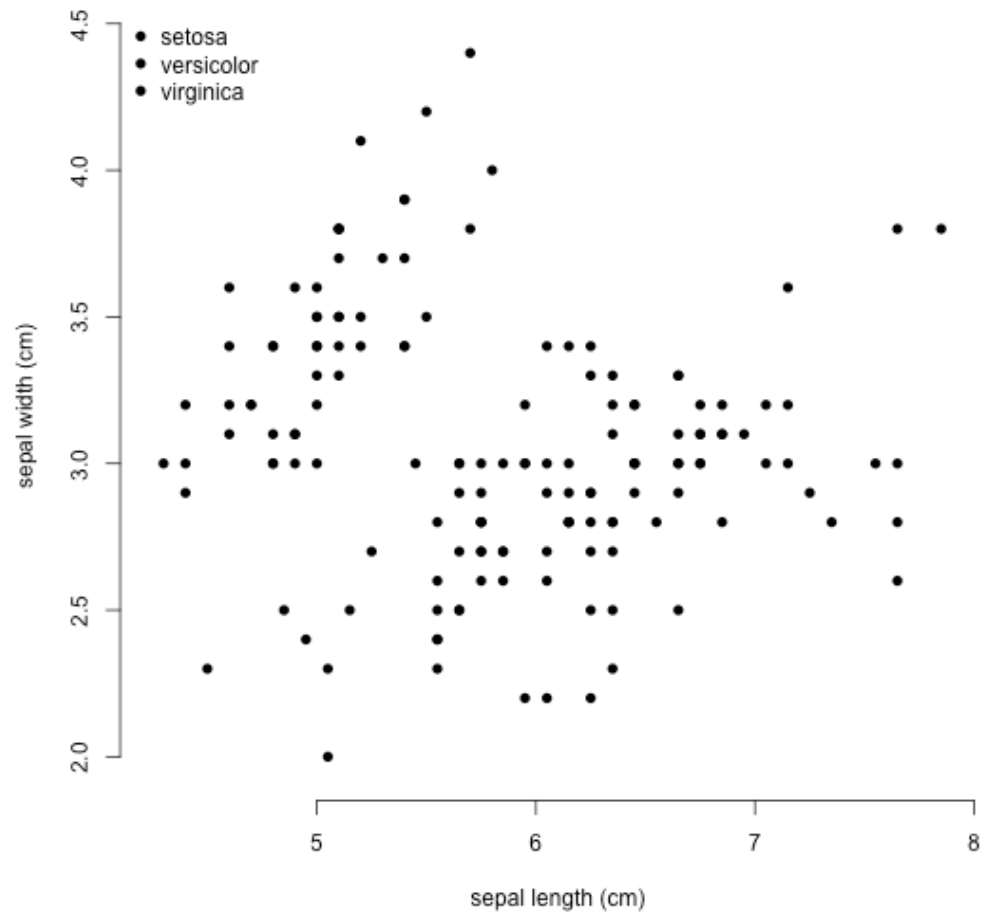
shape



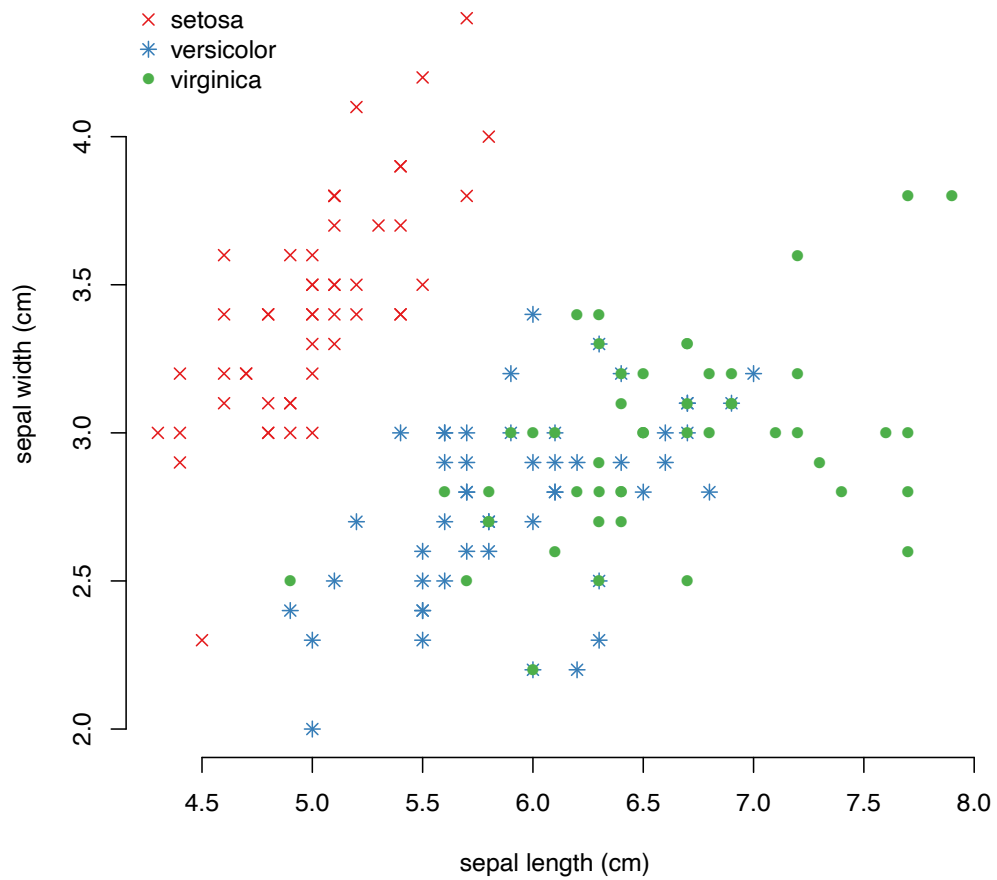
shape + animation



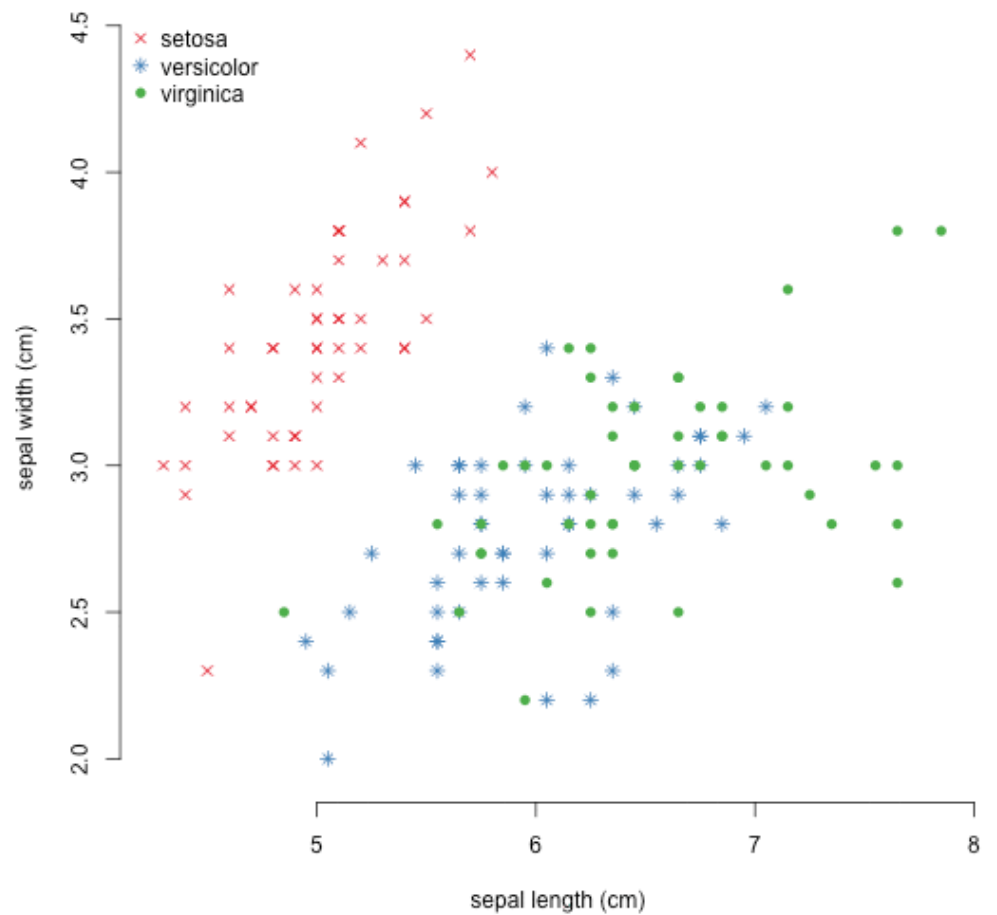
shape + animation



animation



shape + orientation + colour



shape + orientation + colour + animation

How many 3s?

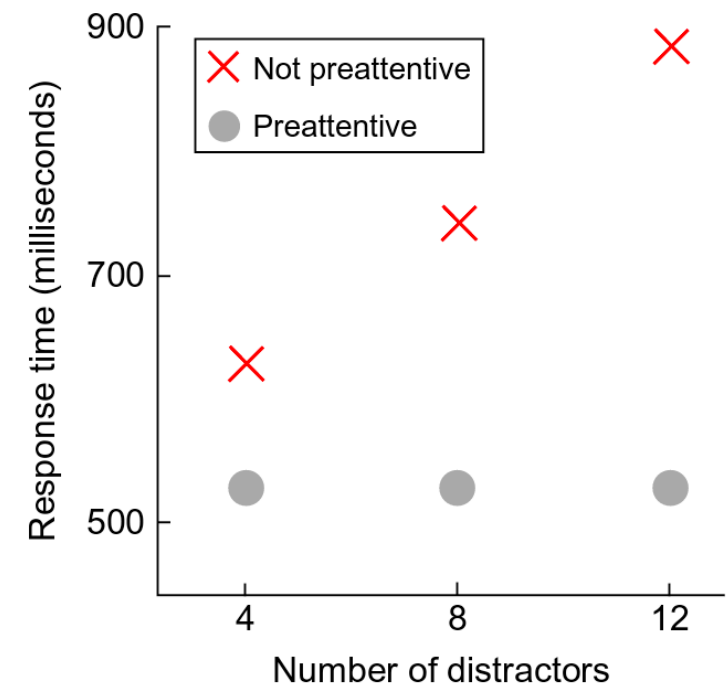
455865876864565749286555584765298742309847249473247
324879427149572389742982479280742938742564875647654
902842968476745464274784674573847648562484789847985

455865876864565749286555584765298742**3**0984724947**3**247
324879427149572**3**897429824792807429**3**8742564875647654
90284296847674546427478467457**3**847648562484789847985

Pre-attentive processing

28287048611426447748601118421026774214547610600508422
68246501542448441001447435424444457112801112724751854
04878144010162846804644444157701444150057441474245606
40414144445676226073707260150046574765460243547575506
18214122254057752132670061837548614445821410444247421

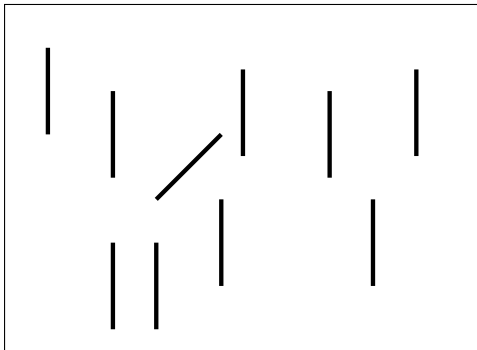
- Some visual objects are processed pre-attentively, before the conscious attention
- Pre-attentive features "pop out"
- Pre-attentive processing speed is independent of the number of distractors
- Processing speed of non-pre-attentive features is slower and the speed decreases as the number of distractors increases (i.e., you must go through all numbers to find 3s)



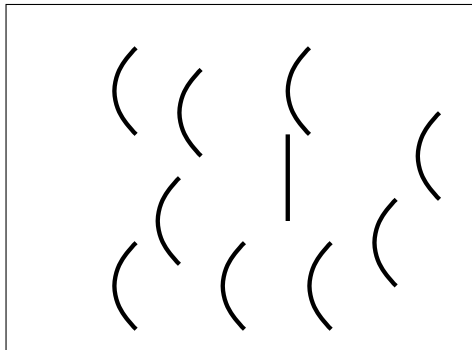
Pre-attentively distinct properties

- **Form** (Line orientation, length, width and collinearity, size, curvature, spatial grouping, added marks, numerosity [up to four])

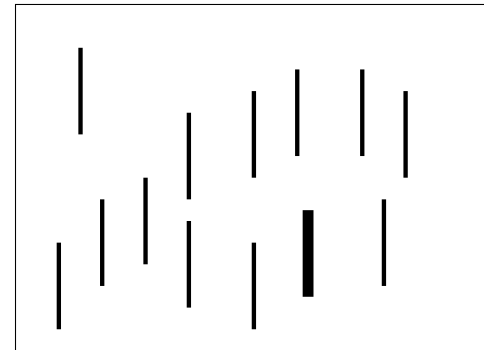
Orientation



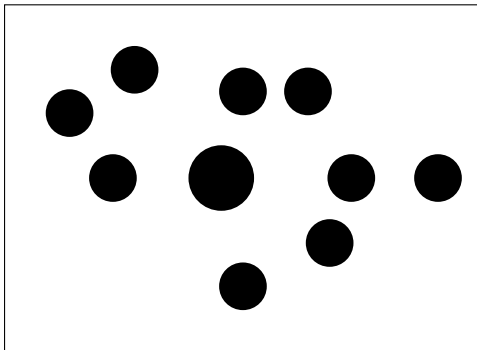
Curved/straight



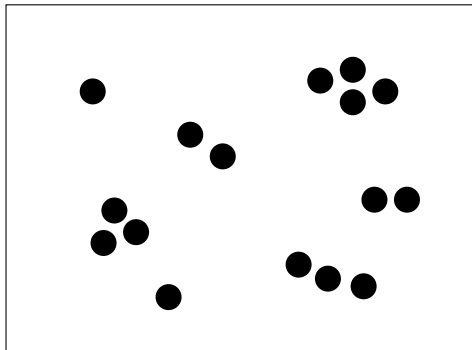
Line width



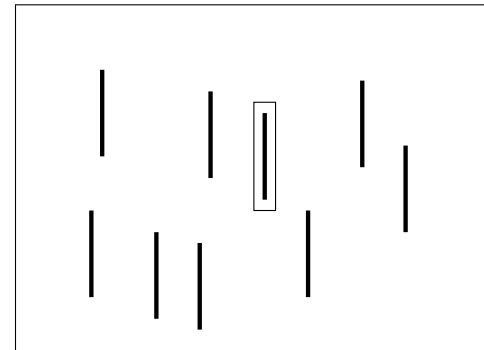
Size



Number

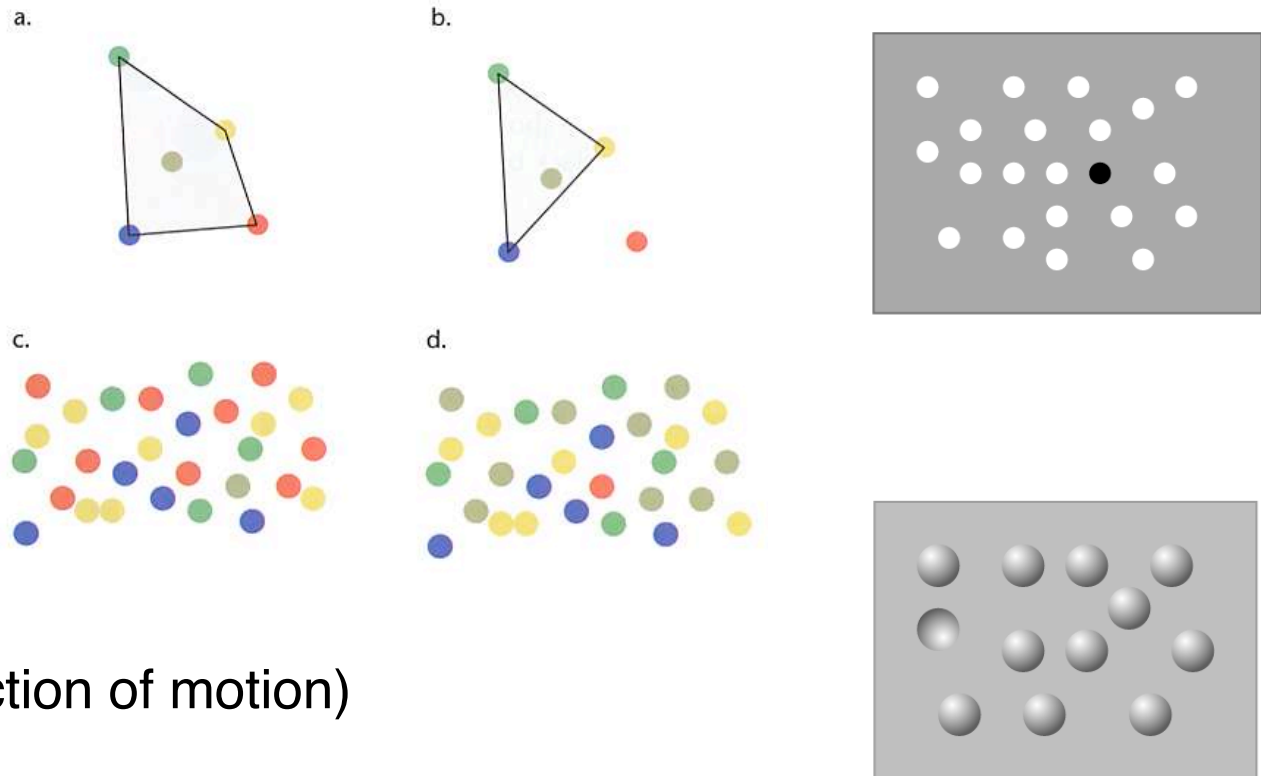


Addition



Pre-attentively distinct properties

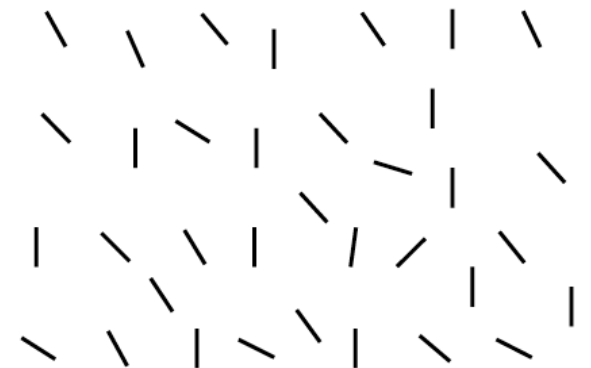
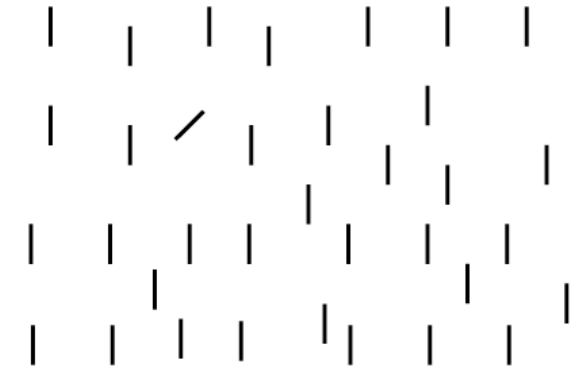
- **Color** (hue, intensity [if outside CIE convex defined by other colors])



- **Motion** (flicker, direction of motion)
- **Spatial position** (2D position, stereoscopic depth, convex/concave form from shading)

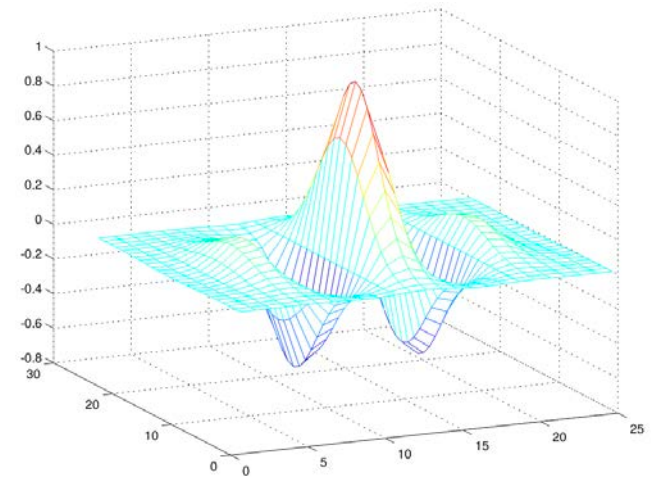
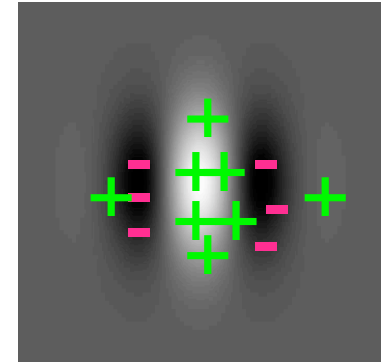
Pre-attentively distinct properties

- Try to find the right-slanted line on the right
- Pre-attentive symbols become less distinct as the variety of distractors increases
- For maximum pop-out, a symbol should be the only object in a display that is distinctive on a particular feature channel
 - e.g., it might be the only item that is coloured in a display where everything else is black and white



Gabor model

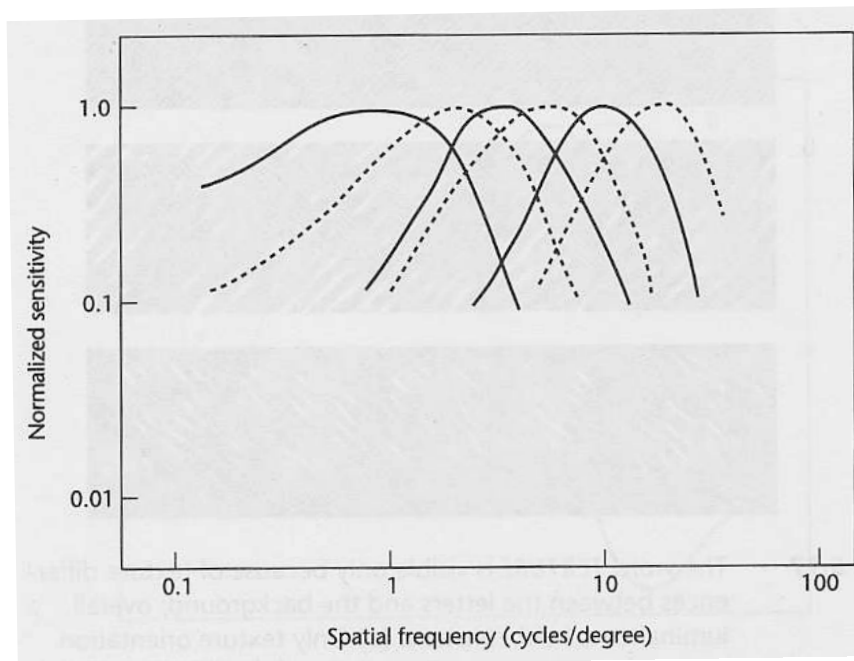
- V1 and V2 contain neurons that can filter **orientation** and **size** information
 - these neurons are tuned to respond best to a specific orientation and size
 - luminance patterns only, no colour!
- The receptive field widths are around two cycles
- Ideal Gabor model has three parameters: contrast (C), orientation (O) and size (S) (or frequency $1/S$).



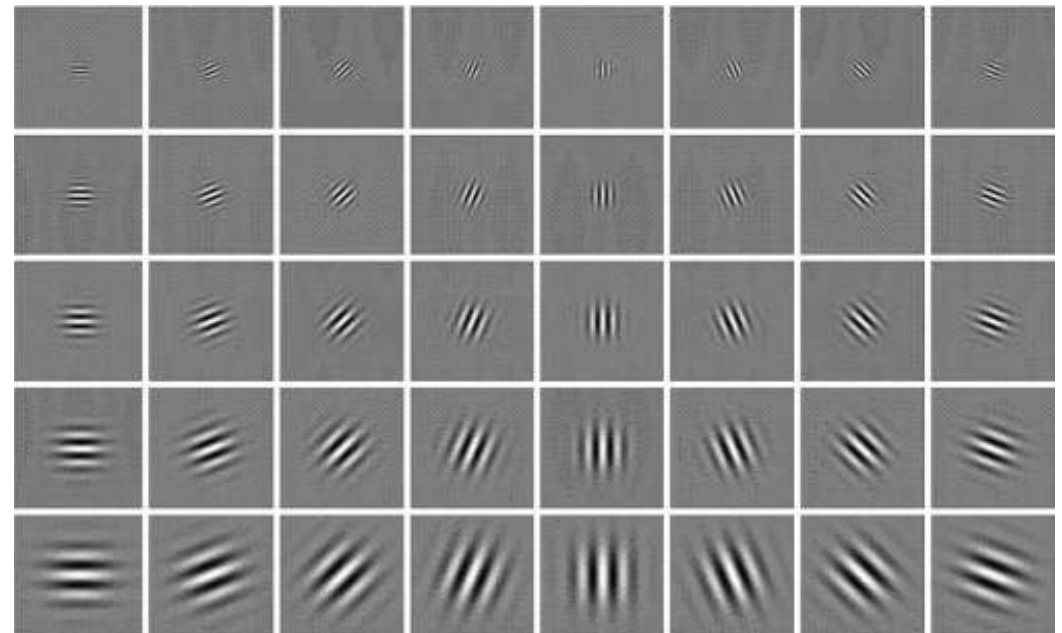
$$\text{Response} = C \cos \left(\frac{\pi}{\sqrt{2}} \frac{Ox}{S} \right) \exp \left(-\frac{1}{2} \frac{\|x\|^2}{S^2} \right)$$

Gabor model

- The parameters scale as follows:
 - **Size (1/frequency)**. Exponential in range $1/16^\circ$ - $1/2^\circ$, c. 4 pre-attentively separable sizes.
 - **Orientation**. Linear in range 0° - 180° , pre-attentive accuracy is c. 30° .
 - **Contrast (amplitude)**.



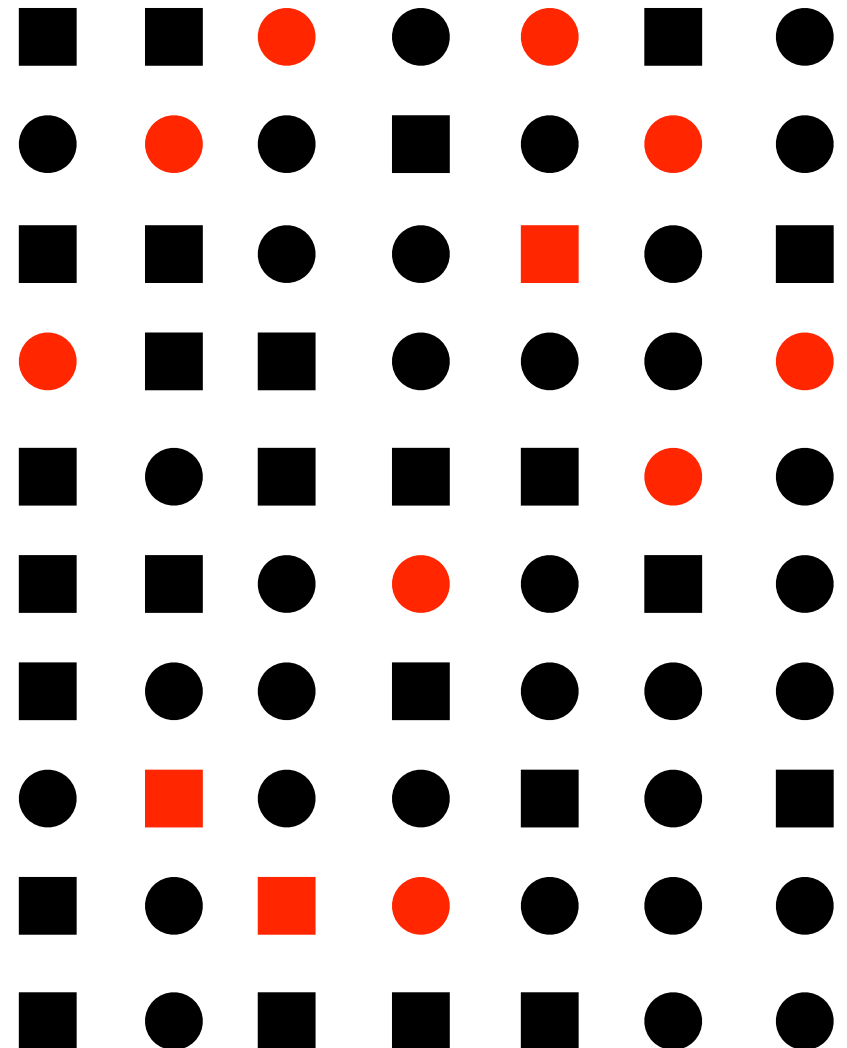
Wilson and Bergen (1983) [W 5.16]



Conjunction searches

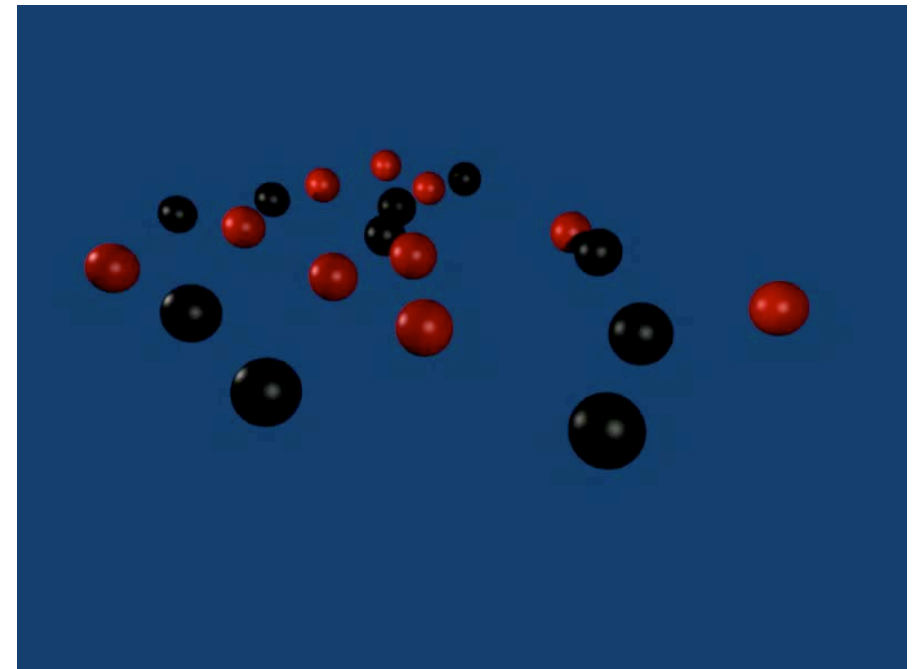
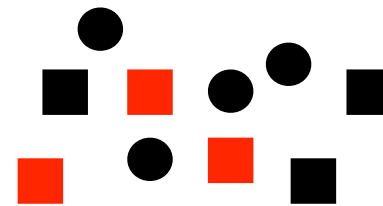
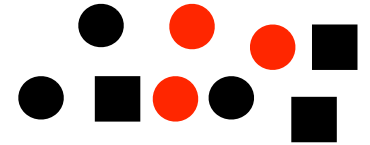
- **Conjunction search** is a visual search that involves searching a specific conjunction of several (2 or more) visual attributes
- Conjunction searches are usually not pre-attentive, even if the individual features are
- Examples:
 - “Find red and square objects” is not pre-attentive search (conjunction search)
 - “Find red objects” is pre-attentive search
 - “Find square objects” is pre-attentive search

How many red squares?



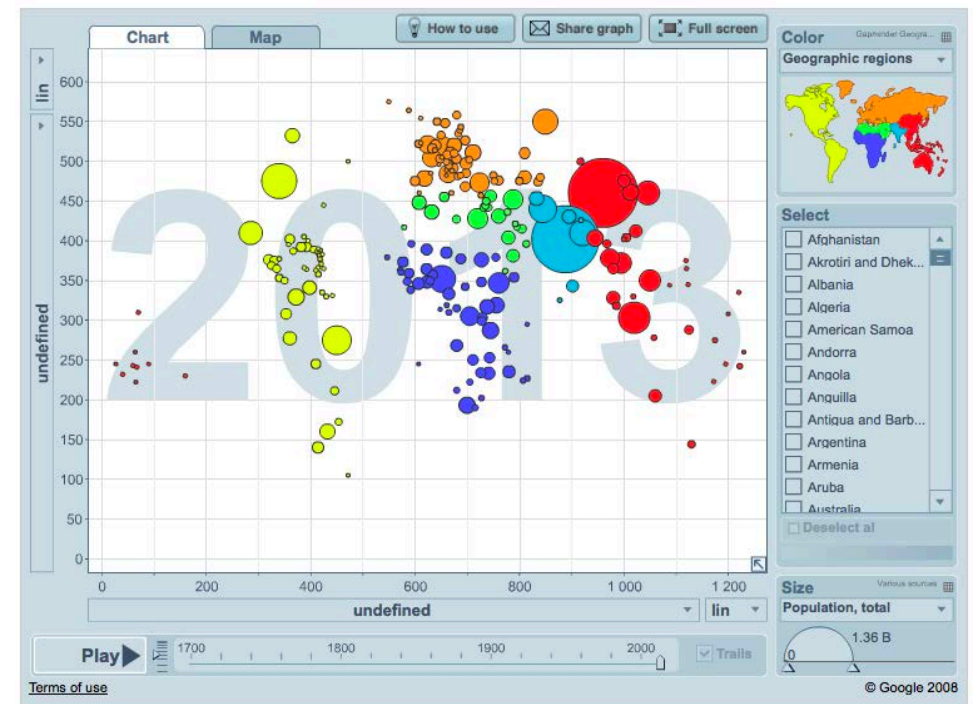
Conjunction searches

- Conjunction searches are usually not pre-attentive
- Some exceptions:
 - spatial grouping on the XY plane (“find red circles”)
 - motion (“find red moving things”)
 - stereoscopic depth
 - combination of convexity/concavity and colour



Glyph design

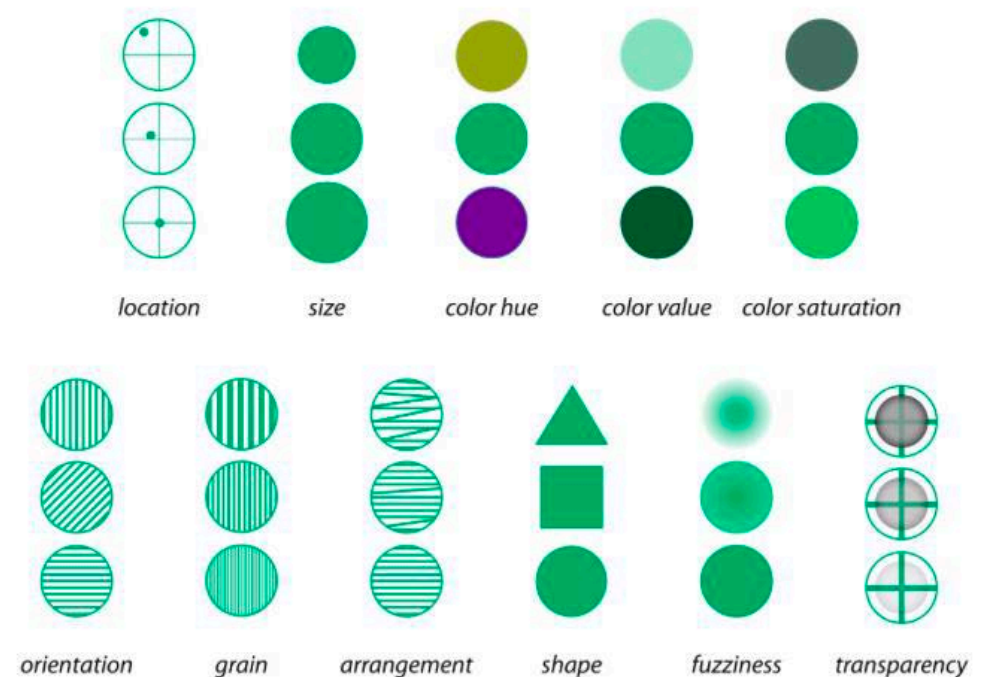
- Glyphs are symbols used to represent multivariate data
- A single glyph corresponds to one sample in a data set
- Data values are mapped to the visual properties of the glyph
- **How to design a glyph so that the data values can be perceived pre-attentively?**



www.gapminder.org

Glyph design

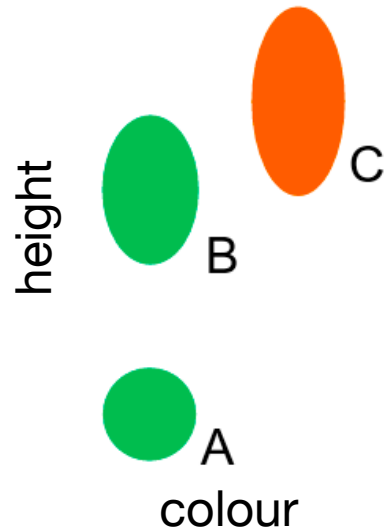
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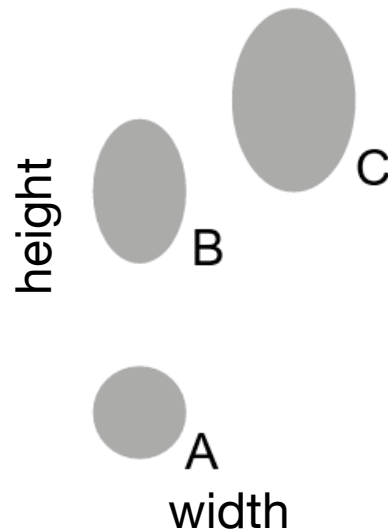
Mackinlay 1986,
<https://doi.org/10.1145/22949.22950>

Integral and separable dimensions

Which two glyphs go best together
(restricted classification task)?

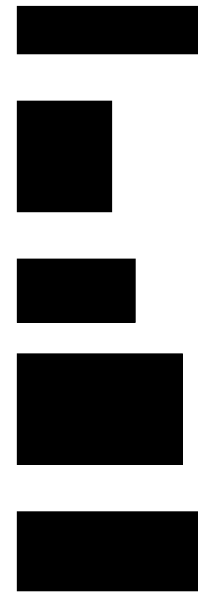


separable features are perceived independent of each other (e.g., size and colour)



integral features are perceived holistically (e.g., a width and height)

Height and random width



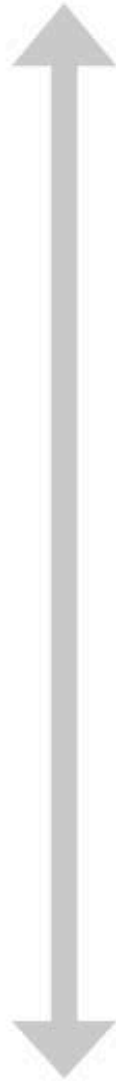
Size and random gray scale



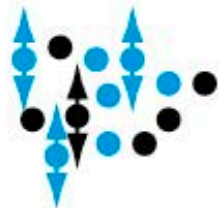
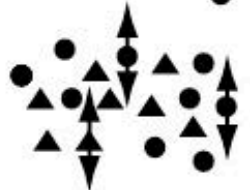
Find ☐ this high rectangle.

*Speeded classification task faster for separable features. **Use separable dimensions to encode different variables in glyphs!***

Integral
dimension pairs



Separable
dimension pairs



Dimension pairs

red-green

yellow-blue

x-size

y-size

size

orientation

color

shape, size, orientation

motion

shape, size, orientation

motion

color

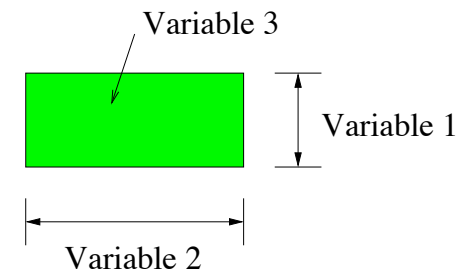
group
location

color

Glyph design: some rules of thumb

- All channels are not independent
 - try to use separable channels
 - in practice the number of channels to be used at once is limited
- If we want pre-attentive processing, we typically have 4-8 resolvable steps in each dimension (e.g., the number of size steps we can easily distinguish is ~4)

Visual variable	Dimensionality
Spatial position	3 (X,Y,Z)
Color of glyph	3
Shape	2-3?
Orientation	(1-)3
Surface texture	3
Motion coding	2-3?
Blink coding	1



Summary on glyph design

- Certain visual features “pop out” (pre-attentive features)
- Data variables should (usually) be mapped to pre-attentive features (they are processed fast)
- Restrictions (if you want pre-attentive design):
 - conjunction searches are usually not pre-attentive
 - one can effectively display only limited number of visual variables, with limited accuracy
 - integral visual dimensions interfere with each other: you should use separable dimensions instead

A model for perceptual processing

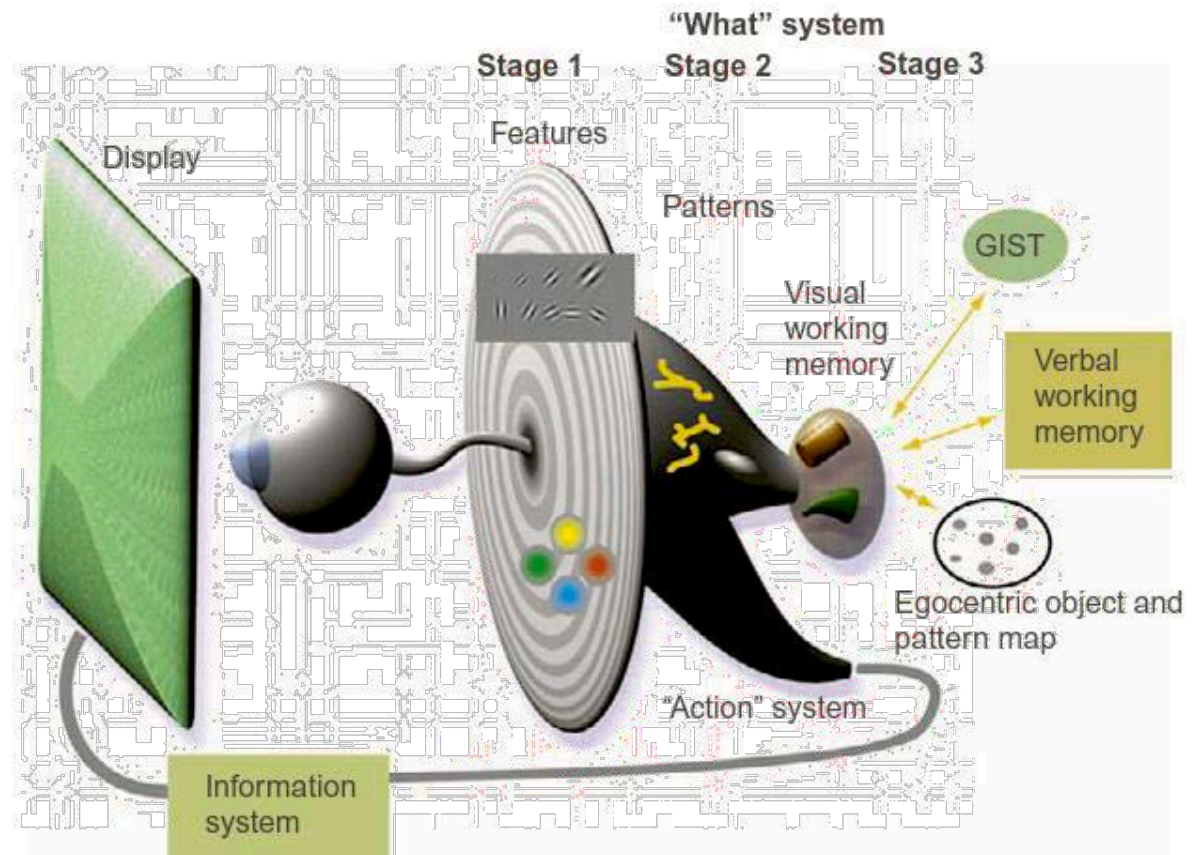
1. Parallel processing to extract low-level properties of the visual scene

- rapid parallel processing
- extraction of features, orientation, colour, texture and movement patterns
- iconic store
- bottom-up, data driven processing

2. Pattern perception

- slow serial processing
- involves both working memory and long-term memory
- arbitrary symbols relevant
- different pathways for object recognition and visually guided motion

3. Visual working memory



Patterns in 2D data

- Exploratory visualization is based on finding patterns from data
- Oversimplification: the patterns are recognized between pre-attentive processing and higher level object perception
- Relevant questions:
 - How do we see groups?
 - How can 2D space be divided into perceptually distinct regions?
 - When are two patterns similar?
 - When do two different elements appear to be related?
- Patterns may be perceived even where there is only visual noise

Gestalt laws

- **Gestalt** is form in German
- The Gestalt School of Psychology (1912 onwards) investigated the way we perceive form
- They produced several Gestalt laws (laws of organisation) of pattern perception
- The Gestalt laws translate directly into design principles of visual displays
- Many of the rules seem obvious, but they are violated often

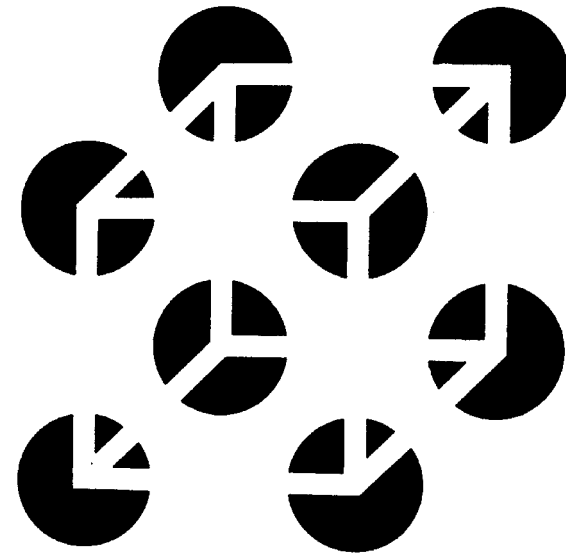


Figure 1. The subjective Necker cube. A phenomenally complete Necker cube can be seen overlying a white surface and eight black discs; so viewed, illusory contours corresponding to the bars of the cube can be seen extending between the discs. The illusory bars of the cube disappear when the discs are seen as 'holes' in an interposing surface, through which the corners of a partially occluded cube are viewed; curved subjective contours are then seen demarcating the interior edges of the 'holes'

Bradley and Petry 1977

Gestalt laws

- Similarity
- Good continuation
- Proximity
- Symmetry
- Closure
- Relative size
- Common fate

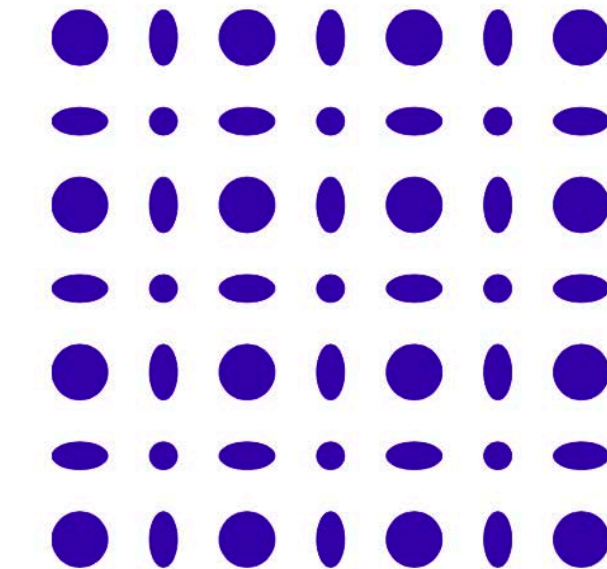
[there are various different lists]

e.g. <https://www.usertesting.com/blog/gestalt-principles>

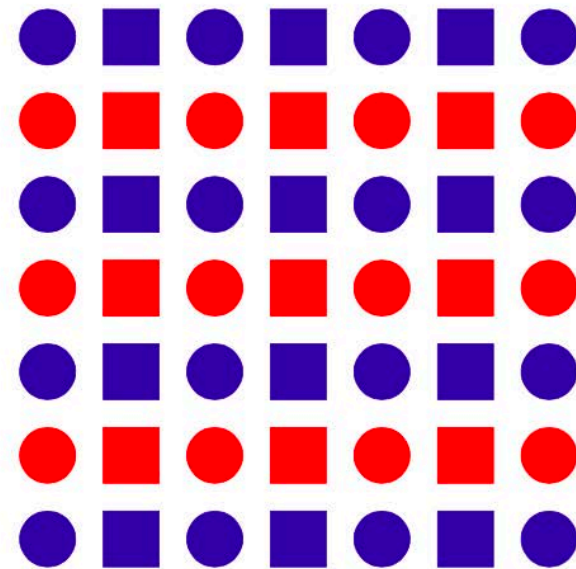
- some “new” motion-based Gestalt(-like) laws:
 - Patterns from motion
 - Animation and perception of shapes
 - Causality

Similarity

- Similar objects appear to be grouped together
- When designing a grid layout of a data set, code rows and/or columns using low-level visual channel properties, such as colour and texture



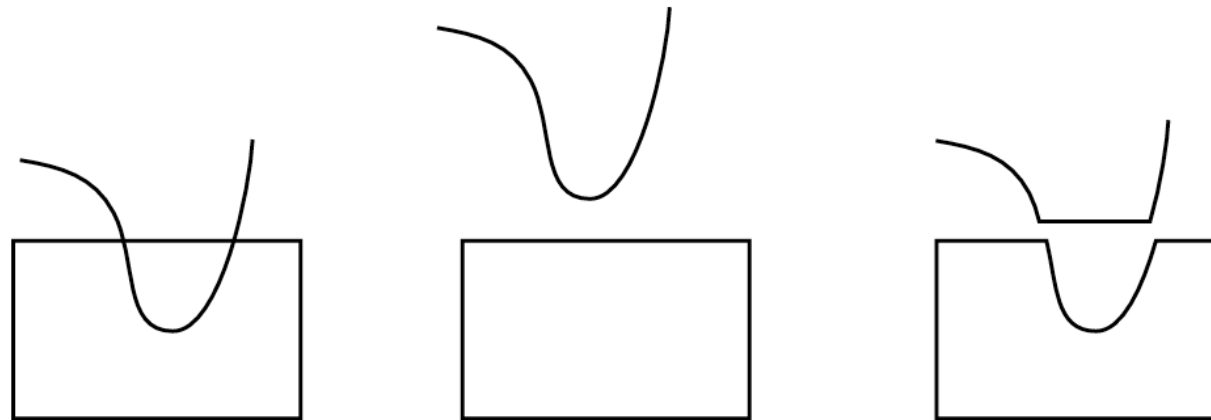
integral dimensions
emphasize overall pattern



separable dimensions
segment rows and columns

Good continuation

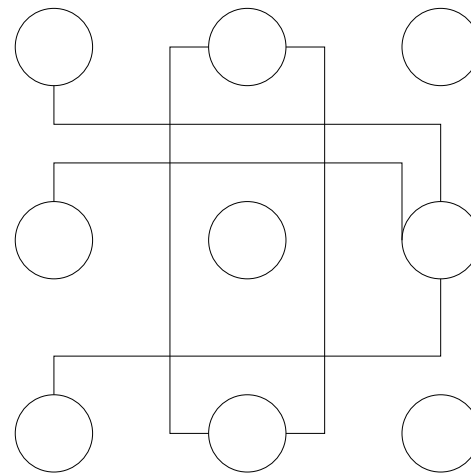
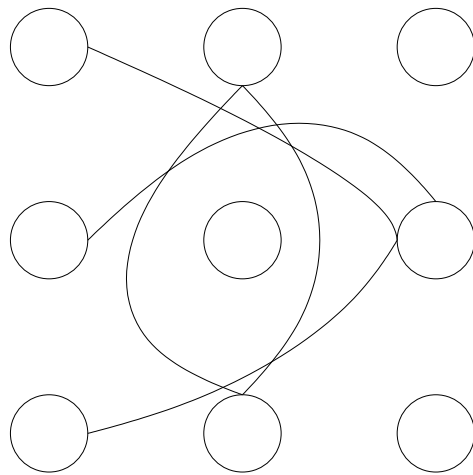
- Visual complete objects are more likely to be constructed from visual elements that are smooth and continuous, rather than ones that contain abrupt changes in direction



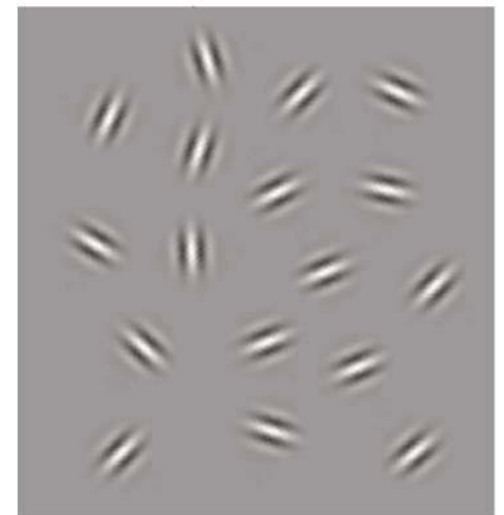
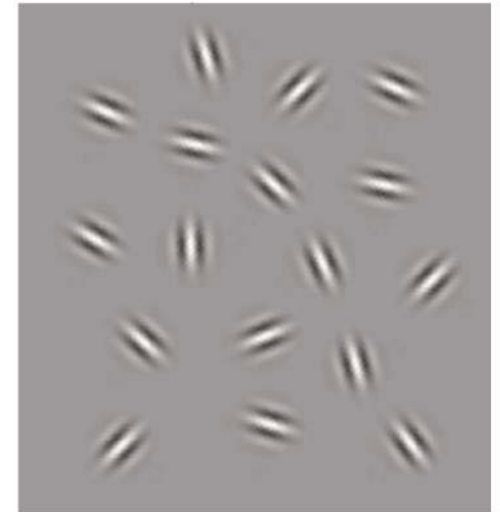
The pattern on the left is perceived as a curve overlapping a rectangle (centre) rather than 2 irregular shapes touching (right).

Good continuation

- Connectedness is one of the most powerful grouping principles
- It is easier to perceive connections when contours run smoothly
- In networks, lines connecting nodes should be smooth and continuous, so they are easier to follow

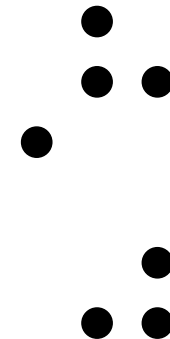
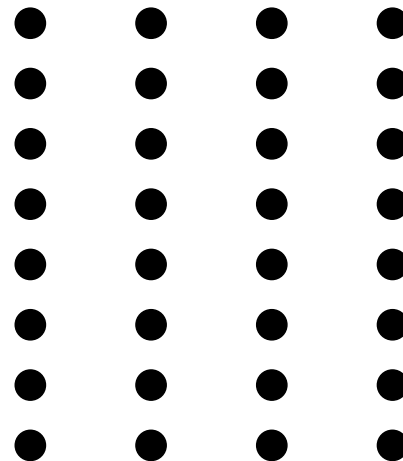
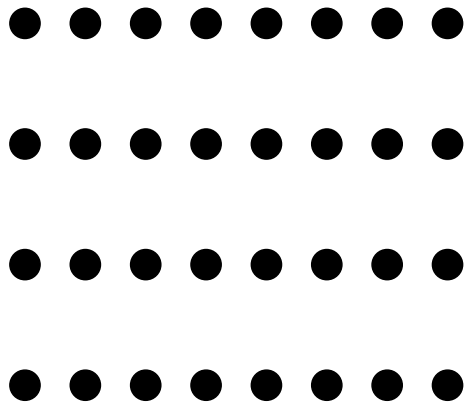


follow the path:



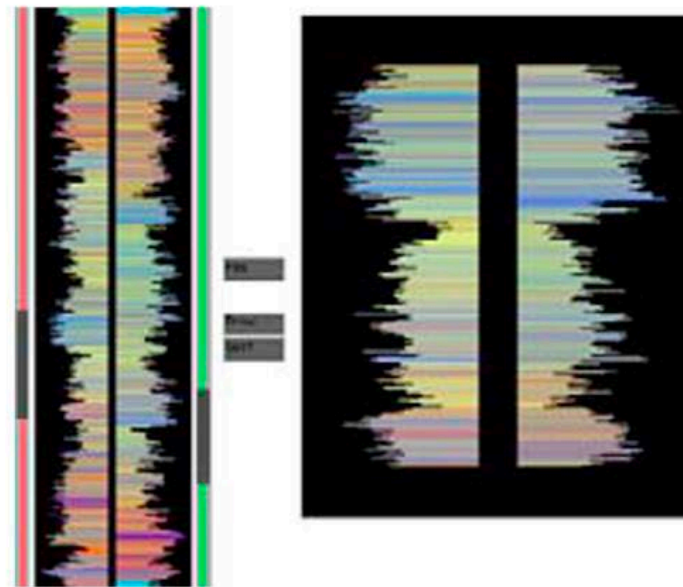
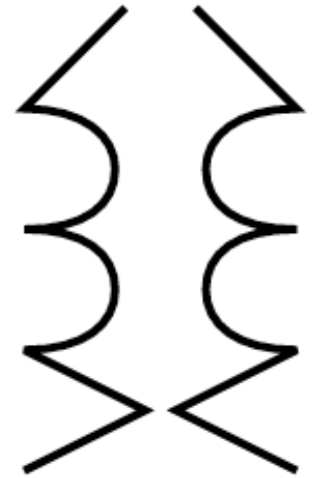
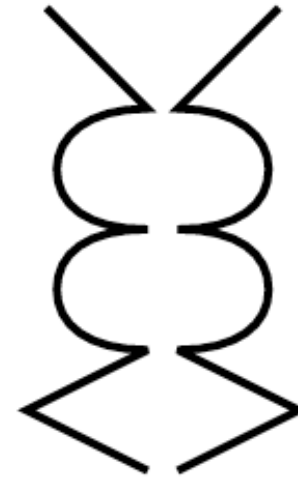
Proximity

- Things that are near to each other appear to be grouped together
- Proximity is one of the most powerful gestalt laws
- Place the data elements into proximity to emphasise connections between them



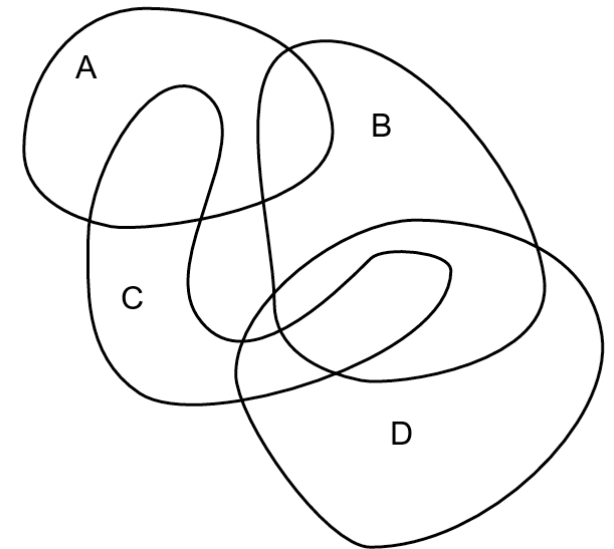
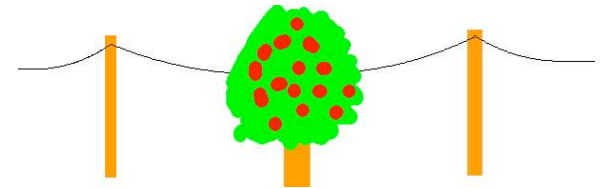
Symmetry

- Symmetrically arranged pairs of lines are perceived together
- Use symmetry to make pattern comparisons easier
- Symmetrical relations should be arranged on horizontal or vertical axes (as symmetries are more easily perceived), unless a framing pattern is used



Closure

- A closed contour tends to be seen as an object
- There is a perceptual tendency to close contours that have gaps in them
- When a closed contour is seen, there is a very strong perceptual tendency of dividing space into a region enclosed by the contour (a common region) and a region outside the contour
- In window-based interface strong framing effects inhibit between-window comparisons: related items should not reside in separate windows

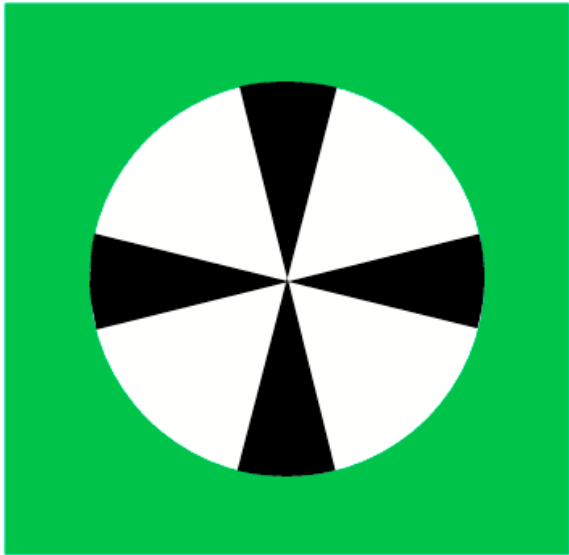


What do you see in this image?
(a famous example of closure)



Relative size, figure/ground

- Smaller components tend to be perceived as an object
- Groupings perceived as overlapping objects



black propeller on
white background

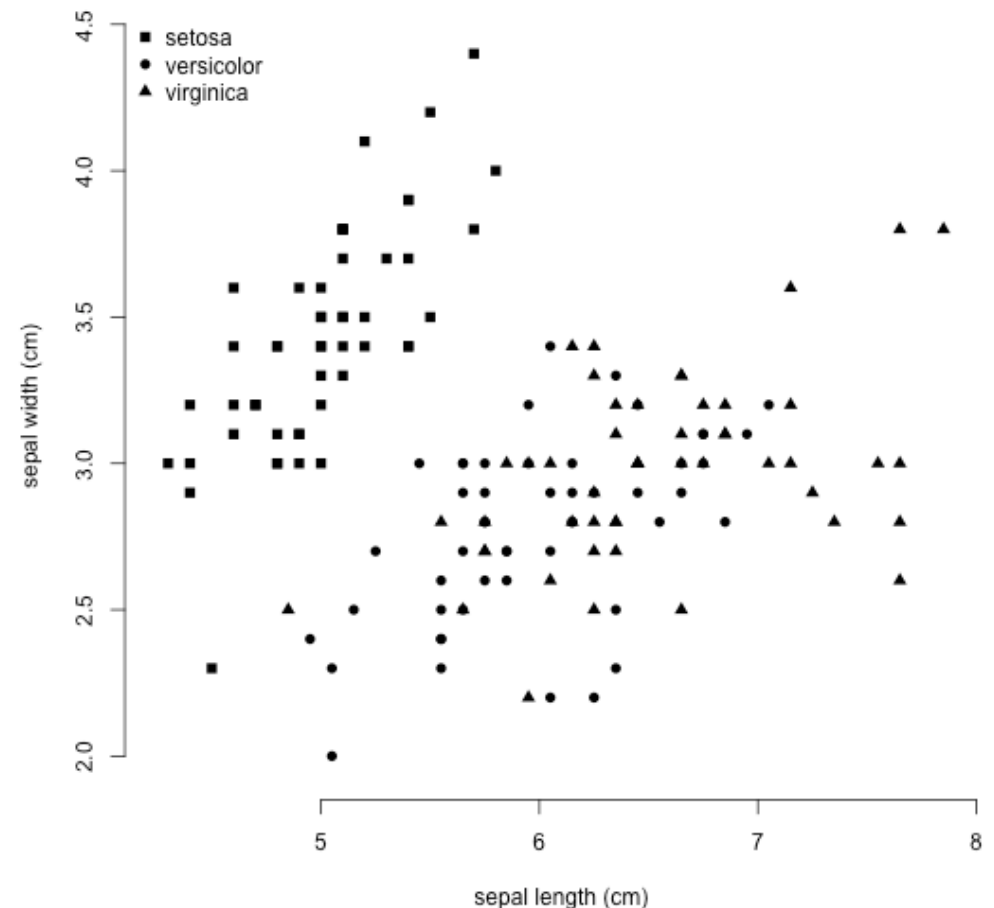


Rubin's reversible
face-vase figure
(multistability)

Ware 2013

Common fate

- Relative motion is an extremely efficient method of showing patterns from data
- Data points oscillate around center point
 - Variables: frequency, phase, amplitude of motion
 - Phase is the most effective variable



Animation and perception of shape

- Gestalt laws also work for animated images: structures and patterns are seen from partial data (as with static images)
- Mystery lights in the dark:



Another example



-
- There is a specific area in human brain for detecting biological motion

See also: <https://www.biomotionlab.ca/html5-bml-walker/>



No delay

Causality

- *Launching*: an object is perceived to set another into motion
- Perception of launching requires precise timing (delays less than 0.07-0.16 s)
- Already infants can perceive causal relations, such as launching



Delay of 0.2 s

Next lecture

- **Interacting with visualisations (Ware Ch 10 + other)**
- **(tentatively) Introduction to dimension reduction**