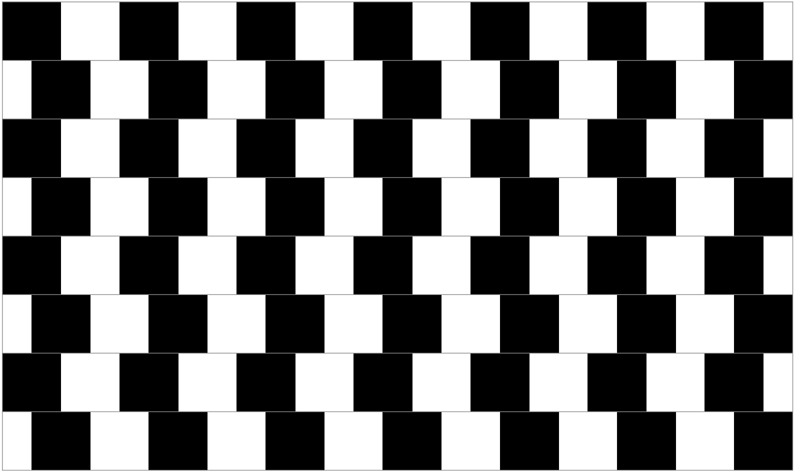
Graphical Perception

Visual Processing And The Brain

- When an image is passed to the brain it is processed through increasingly complex steps until it reaches the higher areas of the brain.
- Very little is known about the detail of these processing steps, but some intriguing information comes from *visual illusions*.
- Illusions appear to to be a result of the brain deriving incorrect information about what is being viewed.
- In more interesting illusions, the brain derives conflicting information about the scene being viewed.

The Cafe Wall Illusion



The Cafe Wall Illusion

- The lines in the image are either horizontal or vertical.
- The illusion stems from the fact that part of our visual processing system is tells us that the lines must be sloping while the cognitive part of our brains tells us they are not.
- This illusion was first noticed by a perceptual psychologist strolling past a group of workmen tiling the wall of a cafe in Bristol, UK.

The (Real) Cafe Wall Illusion

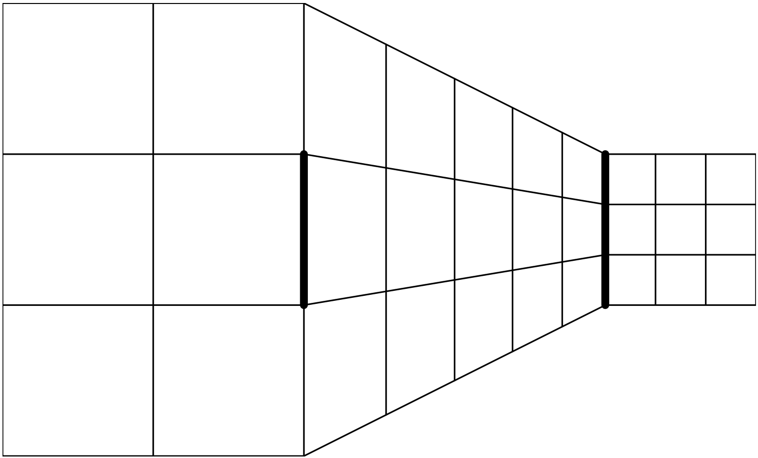
Types of Illusion

- Illusions come in a variety of forms.
- Geometric illusions are among the most interesting. Such illusions include:
  - distortions of lengths
  - distortions of angles
  - distortions of areas
  - distortions of shapes

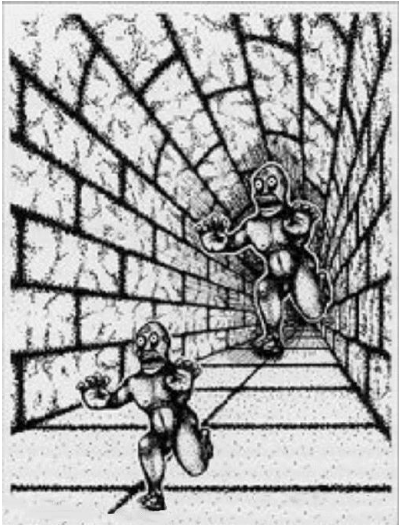
Perspective Illusions

- A number illusions result from the visual system interpreting visual elements as giving information about depth.
- Perspective gives us very strong depth cues.
- Misinterpreting geometric features as resulting from perspective produces strong distortions.

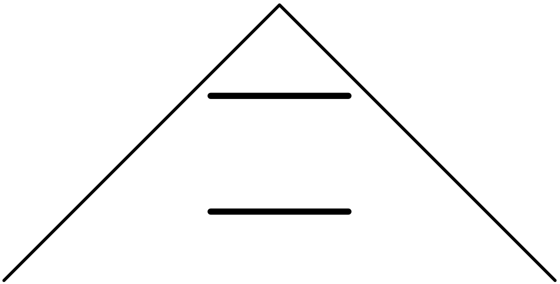
A Perspective Illusion



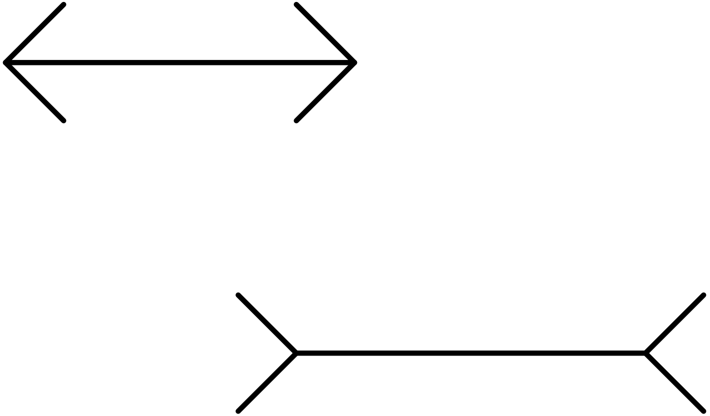
Another Perspective Illusion



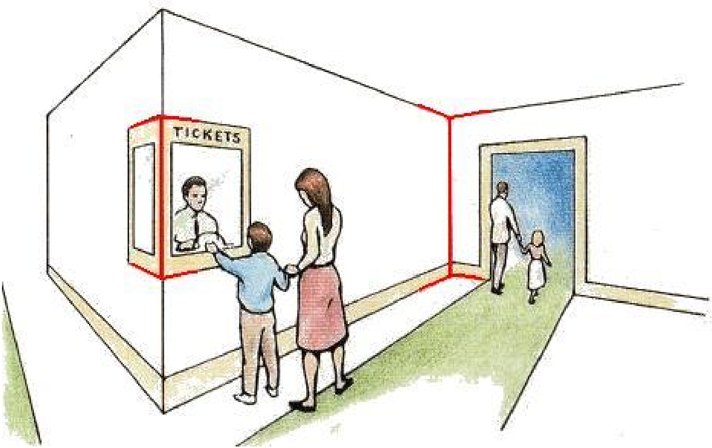
The Ponzo Illusion



The Müller-Lyer Illusion



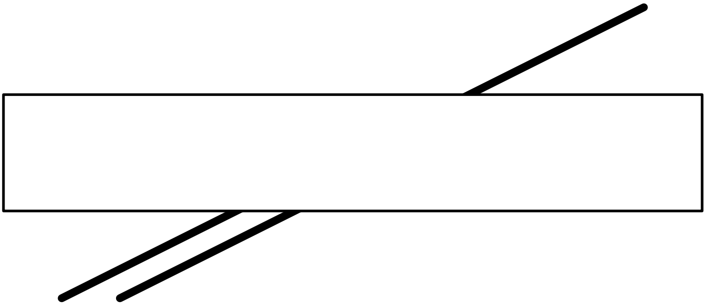
A Possible Source Of The Müller-Lyer Illusion



Angle Distortion Illusions

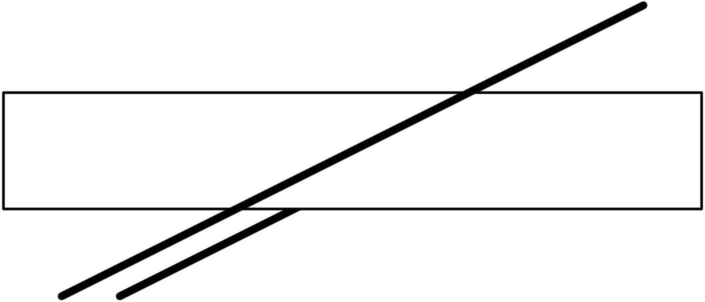
- The next group of illusions shown how angles can be misperceived by our visual systems.
- This is of some interest in presentation graphics.

The Poggendorf Illusion



Which of the two lower lines
is the extension of the upper line?

The Poggendorf Illusion

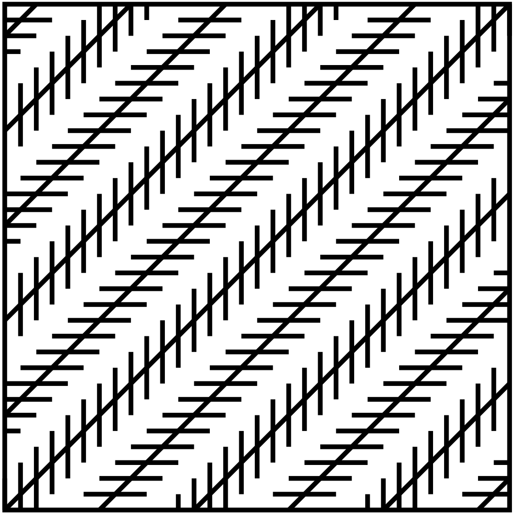


Which of the two lower lines
is the extension of the upper line?

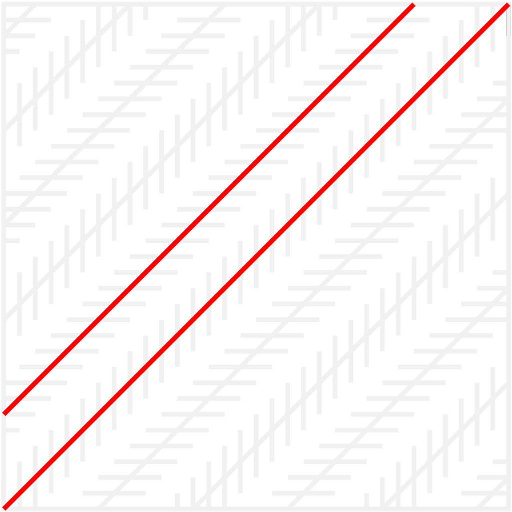
Explanation

- It appears that we have a tendency to overestimate the size of acute angles and to underestimate the size of obtuse ones.
- This effect is shown in the one of the Yarbus experiments shown in the last lecture.
- A variety of illusions result from this misjudgement.

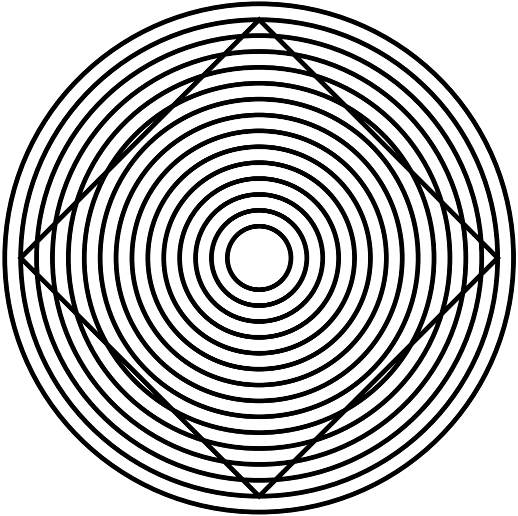
The Zöllner Illusion 1



The Zöllner Illusion 2



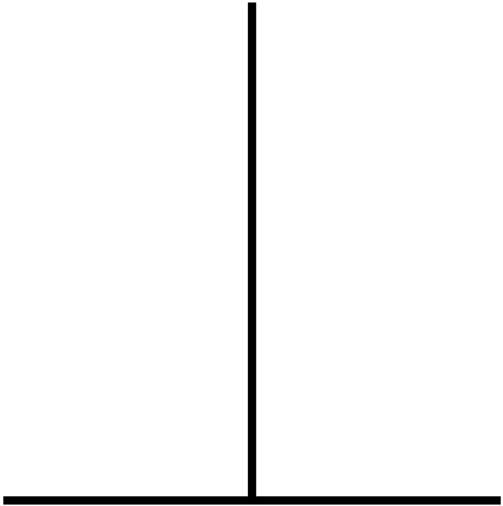
The Ehrenstein Illusion



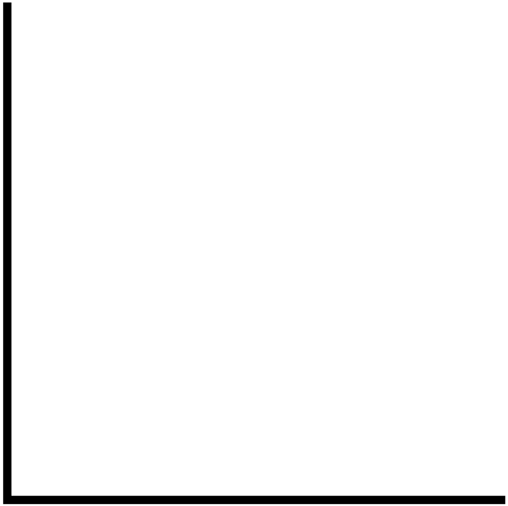
Size Illusions

- Perspective cues can lead us to misjudge the size of objects.
- This is not the only way in which we can be mislead about the sizes.
- The are a number of size illusions which happen in purely two-dimensional diagrams.

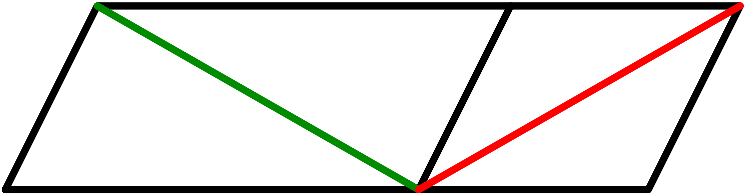
The Horizontal-Vertical Illusion



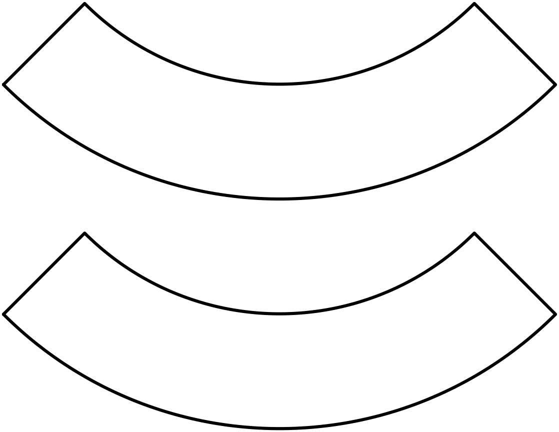
The Horizontal-Vertical Illusion



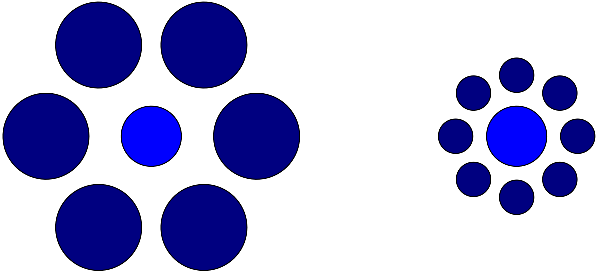
A Line Length Illusion



The Jastrow Illusion



Tichener Illusion

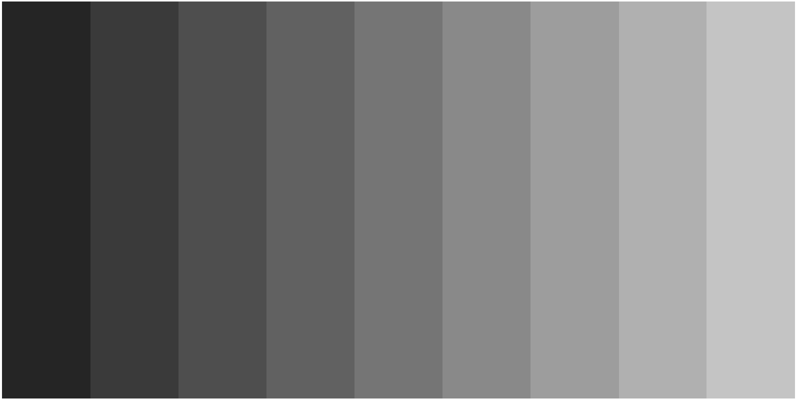


Colour Illusions

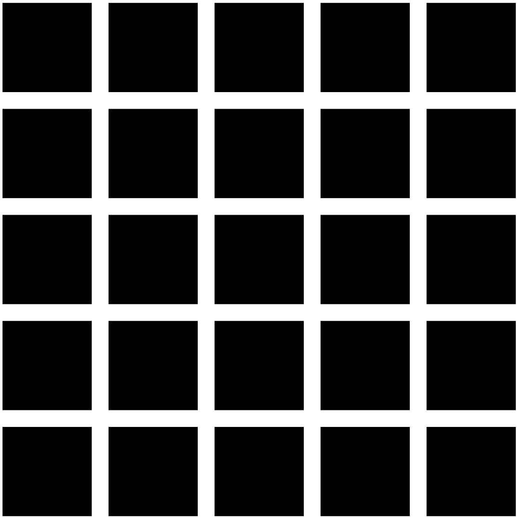
- There are many illusions related to colour.
- Many of these are due to the fact that we do not see colour in isolation, but relative to its surrounding colour.
- Often this can be explained as a result of lateral inhibition.

An Irradiation Illusion

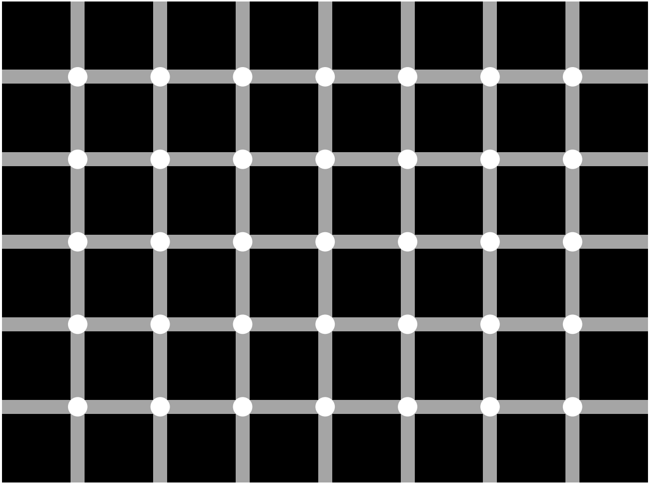
Mach Banding



The Hermann Grid



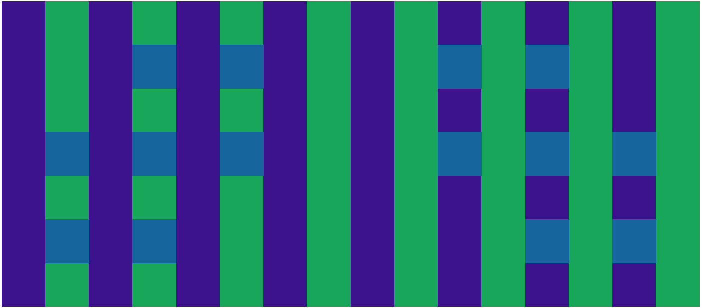
Elke Lingelbach’s Variant of the Hermann Grid



Simultaneous Contrast I

The appearance of colours depends on their surroundings.

Simultaneous Contrast II



Simultaneous Contrast III

Graphical Perception

- Some visual processing takes place without any concious effort on our part.
- Psychologists call this *preattentive vision*.
- In the context of extracting information from graphs we will call it *graphical perception*.
- Graphs which convey their information at this unconcious level allow us to extract the information without any concious effort on our part.
- Such graphs are said to provide *inter-occular traumatic impact* (this is a joke).

Graphical Cognition

- Some visual processing requires that we conciously inspect the things that we are looking at.
- Psychologists refer to this kind of activity as *cognitive*.
- It is *graphical cognition* which allows us to make statements like
  - The largest person is third from the right.
  - The steepest slope in the graph is near $x = 4.5$.

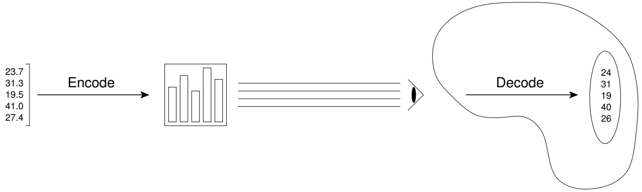
Graphical Design

- Graphs can affect us at either the perceptual or cognitive level (or both).
- The most effective (and eye-catching) graphs always operate to some extent at the perceptual level.

Graph Drawing

- When we draw a graph we *encode* a numerical value as a graphical attribute.

- When we look at a graph the aim is to *decode* the graphical attributes and extract information about the numbers which were encoded.

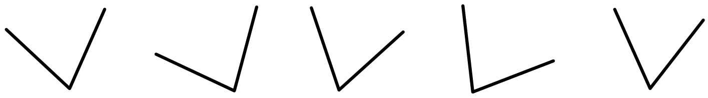


- If possible we should arrange for the decoding to happen at the perceptual level.

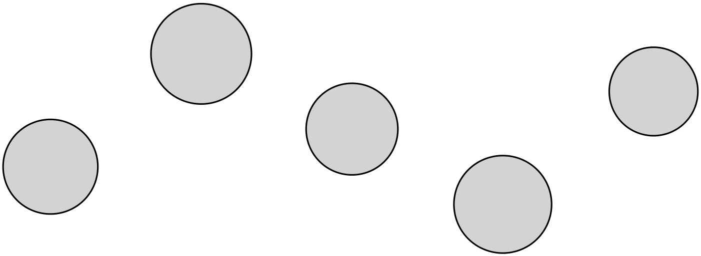
Designing Effective Graphs

- To design effective graphs we must know which graphical attributes are most easily decoded.
- We need a selection of possible graphical attributes and an ordering of their ease of decoding.
- There are a number of possibilities.

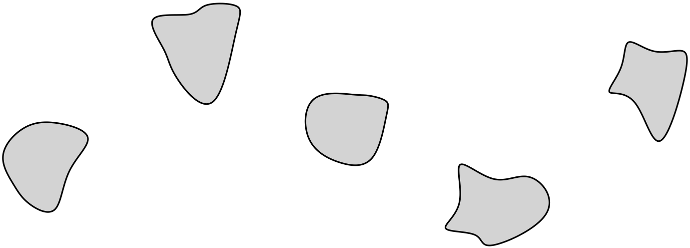
Encoding Using Angles



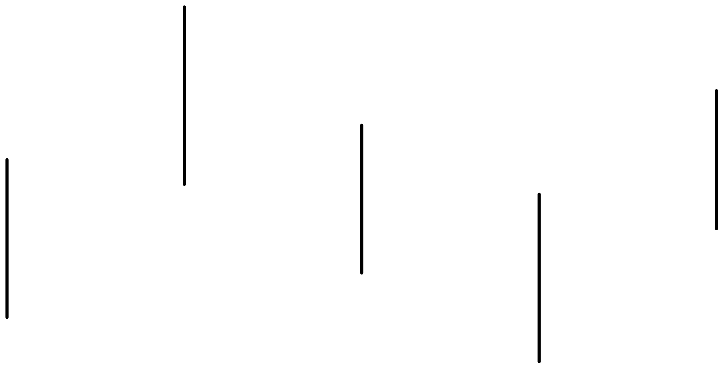
Encoding Using Circle Areas



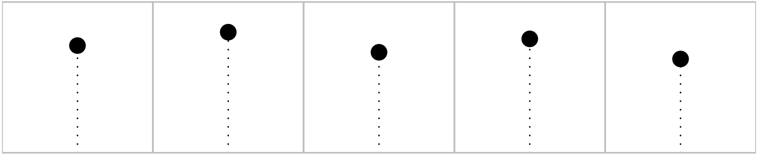
Encoding Using Irregular Areas



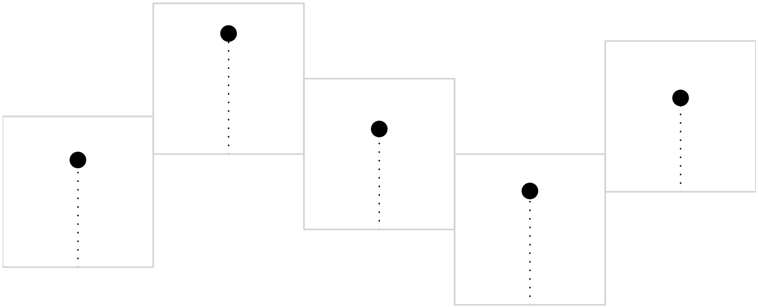
Encoding Using Lengths



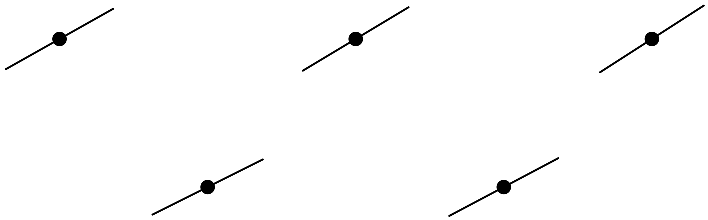
Position on a Common Scale



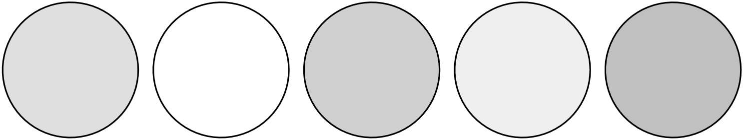
Position on Identical but Unaligned Scales



Encoding Using Slopes



Encoding Using Luminance



Perception “Laws”

- Perceptual psychologists have established a number of empirical laws for perception.
- The two most important laws hold very generally and apply to many graphical encodings.

Weber's Law I

Weber's law applies to a variety of perceptual encodings, but we will apply it to length.

- Consider two lines with lengths x and $x + w$.
- If w is very small, there is only a very small chance that we will notice that the lines have different lengths.
- As w gets larger, the chance of detecting a difference increases.
- Weber's law says that the chance of detecting a difference depends on the value of w/x.

Weber's Law II

- For a given individual the difference between x and $x + w$ will be detected with probability $p_x(w)$.
- Now turn this around. For a fixed p, let the value of w which is detected with this probability be

$$w_p(x)$$

- Weber's law states that

$$w_p(x) = k_p x$$

- Since $w_p(x) \propto x$, we detect *relative* differences in values.

Weber's Law III

- We detect a 1cm change in a 1m length as easily as we detect a 10m change in a 1km length.
- Weber's law appears to hold for many different graphical encodings.

Stevens' Law

- Suppose that we encode a value x and then decode it to obtain a perceived value $p(x)$.
- Stevens' law says

$$p(x) = Cx^{\beta}$$

- The values of C and β depend on both the encoding method used and the observer.
- This law holds for many encodings.

Power Coefficient and Nonlinearity

- If the relationship $p(x)$ and x is nonlinear, we can be mislead in what we infer about the x values.

- The linearity of the relationship between $p(x)$ and x depends only on the value of β, with linearity if and only if $\beta = 1$.

- Here are some typically observed ranges for β.

Length:	0.9 – 1.1
Area:	0.6 – 0.9
Volume:	0.5 – 0.8

Stevens' Law – Perception of Large Values

- Consider area with $\beta = 0.7$.
- Suppose that we compare an area of size 2 with an area of size 1. The perceived ratio of areas is:

$$\frac{p(2)}{p(1)} = \frac{2^{0.7}}{1^{0.7}} = 1.62$$

- We don't see the bigger area as twice as large.

Stevens' Law – Perception of Small Values

- Consider area with $\beta = 0.7$.
- Suppose that we compare an area of size $1/2$ with an area of size 1. The perceived ratio of areas is:

$$\frac{p(1/2)}{p(1)} = \frac{0.5^{0.7}}{1^{0.7}} = 0.62$$

- We don't see the smaller area as half the size.

Perception of Area and Volume

- Our perception of areas and volumes is conservative.
- When values are presented as areas or volumes, we underestimate the large values relative to the small ones and overestimate the small ones relative to the large ones.

Combining Weber's and Stevens' Laws

Consider encoding using length with $\beta = 1$ and area with $\beta = 0.7$. When we compare the values x and $x + d$ we perceive the relative value

$$\frac{x+d}{x} = 1 + \frac{d}{x}$$

for length and the relative value

$$\frac{(x+d)^{0.7}}{x^{0.7}} = \left(1 + \frac{d}{x}\right)^{0.7} \approx 1 + \frac{0.7d}{x}$$

for area.

We are more likely to detect small differences when a length encoding is used than when area encoding is used.

Ranking Graphical Encodings

- Cleveland and McGill carried out an extensive study of graphical encodings to obtain a best to worst ranking.
- The rankings they examined were

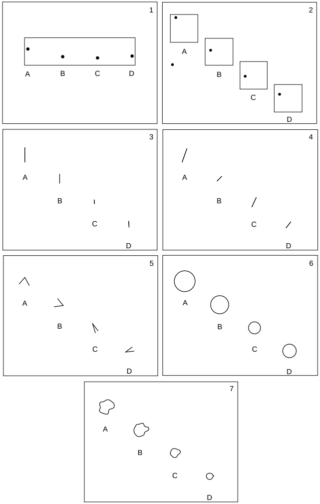
    angle, area, colour hue, length,
    colour brightness,
    position (common scale),
    position (identical unaligned scales),
    colour purity,
    slope, volume

One Cleveland and McGill Experiment

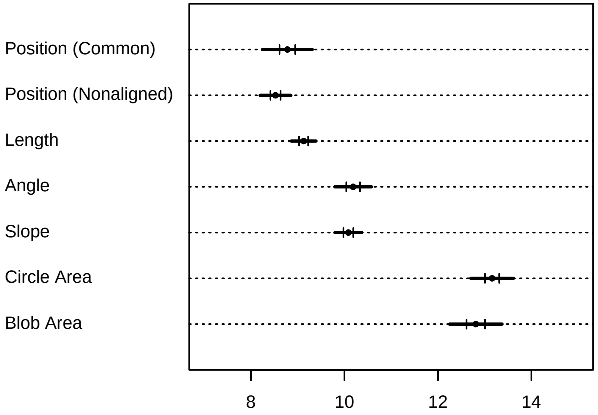
- 7 graphical encodings
- 3 judgements per encoding
- 10 replications per subject
- 127 experimental subjects
- Assessment criterion:

$$\text{error} = |\text{judged}\% - \text{true}\%|$$

One Cleveland and McGill Experiment



Results


Position (Common)
Position (Nonaligned)
Length
Angle
Slope
Circle Area
Blob Area
8
10
12
14

The Encoding Ranking

1. Position on a common scale
2. Position along identical, non-aligned scales
3. Length
4. Angle / Slope
5. Area
6. Volume
7. Colour properties

Recommendations

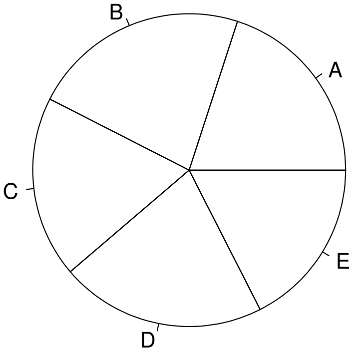
- Use the highest possible encoding on the Cleveland-McGill scale.
- The preferred encodings are:
  - Position on a common scale.
  - Position on identical, unaligned scales.
  - Length.
- Be careful when using angles and slopes when encoding numerical values.
- Don’t use area or volume to encode numerical values.
- Don’t use colour to encode numerical values.

Perception In Maps

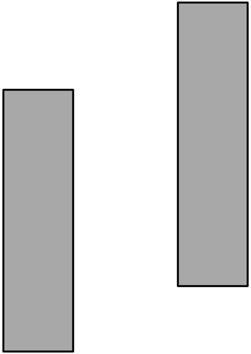
Our perception of the size of areas is affected by the shape of those areas. Here Georgia is bigger than Florida, but doesn't look it.

Angular Encoding in a Pie Chart

Pie charts have a very weak perceptual basis.



Encoding Using Length



Encoding Using Identical Unaligned Scales