



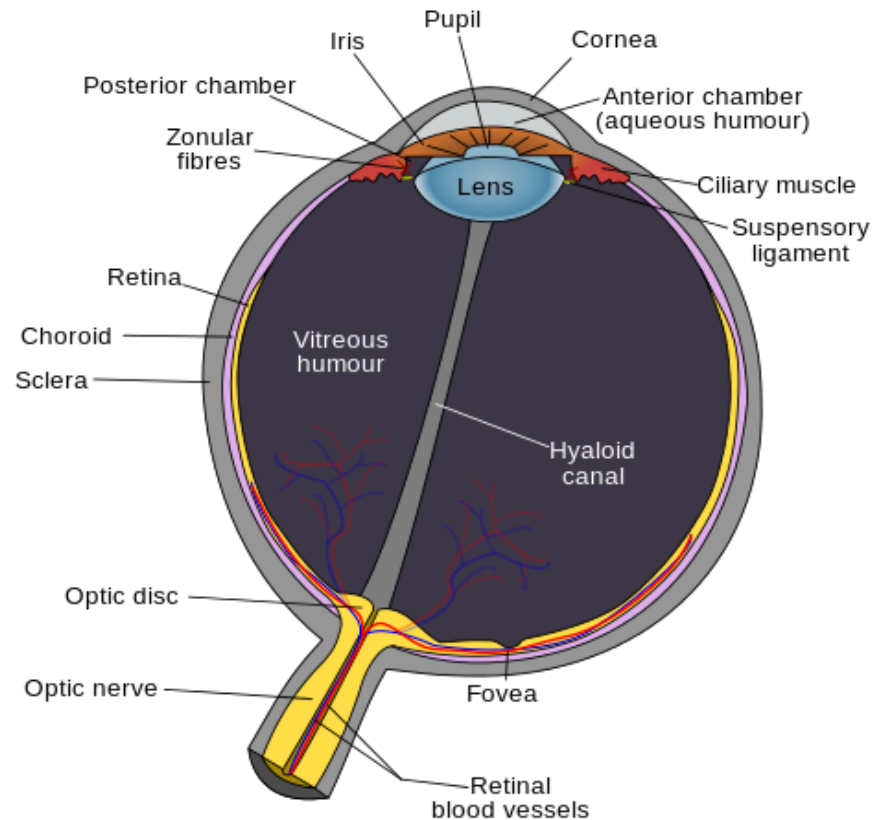
S. Rinzivillo – [rinzivillo@isti.cnr.it](mailto:rinzivillo@isti.cnr.it)

# **DATA VISUALIZATION AND VISUAL ANALYTICS**



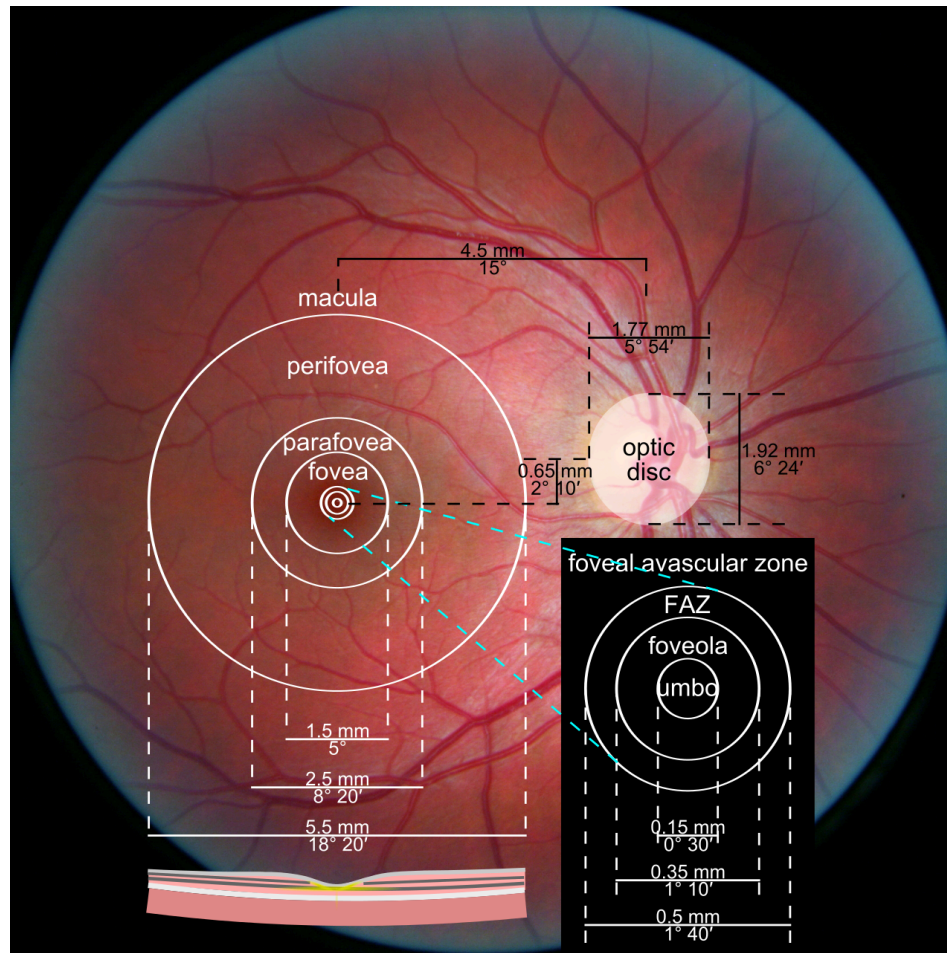
# **VISION AND PERCEPTION**

# Human Eye



"Schematic diagram of the human eye en" by Rhcastilhos - Schematic\_diagram\_of\_the\_human\_eye\_with\_English\_annotations.svg. Licensed under Public Domain via Wikimedia Commons - [http://commons.wikimedia.org/wiki/File:Schematic\\_diagram\\_of\\_the\\_human\\_eye\\_en.svg#mediaviewer/File:Schematic\\_diagram\\_of\\_the\\_human\\_eye\\_en.svg](http://commons.wikimedia.org/wiki/File:Schematic_diagram_of_the_human_eye_en.svg#mediaviewer/File:Schematic_diagram_of_the_human_eye_en.svg)

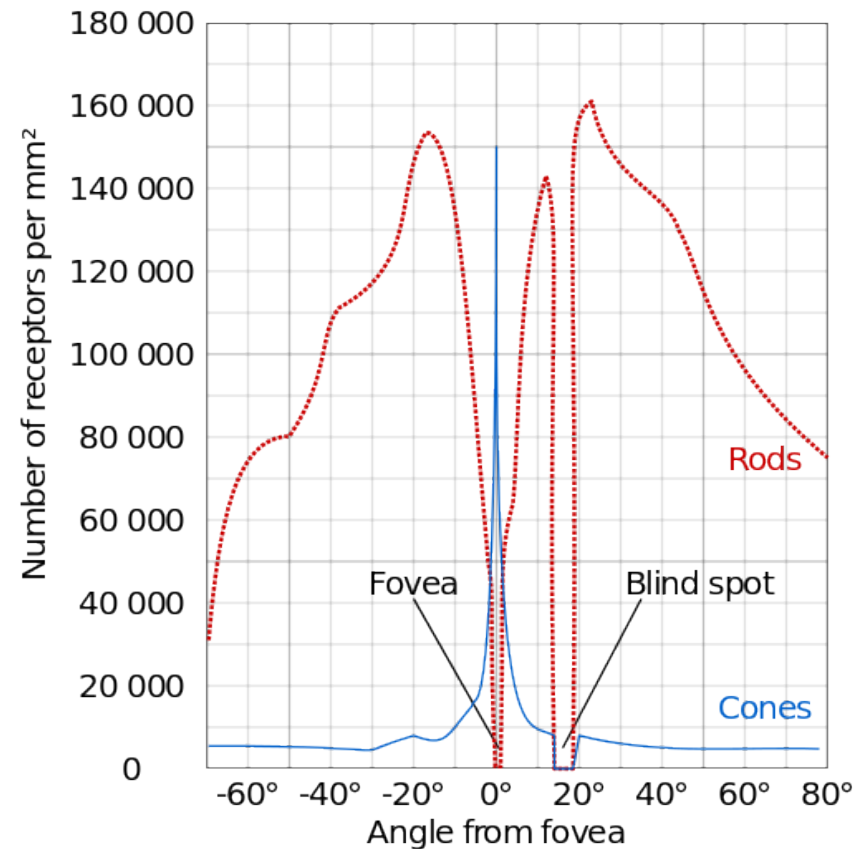
# Macula and Fovea



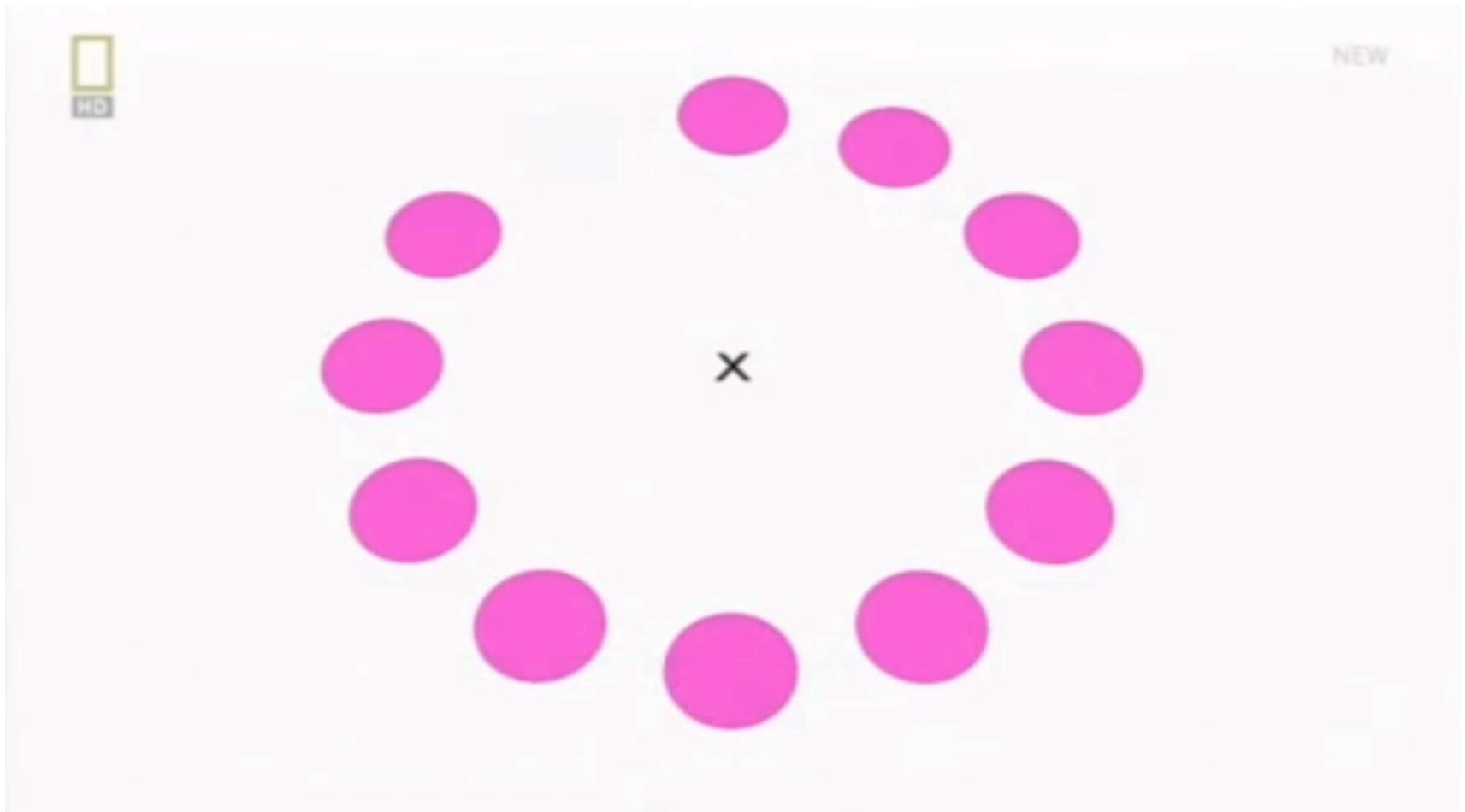
"Macula" by Photograph: Danny Hope from Brighton & Hove, UK -  
File:Right\_eye\_retina.jpg (which come from My Right Eye). Licensed under CC BY  
2.0 via Wikimedia Commons - [http://commons.wikimedia.org/wiki/  
File:Macula.svg#mediaviewer/File:Macula.svg](http://commons.wikimedia.org/wiki/File:Macula.svg#mediaviewer/File:Macula.svg)

# Photo Receptor Cells

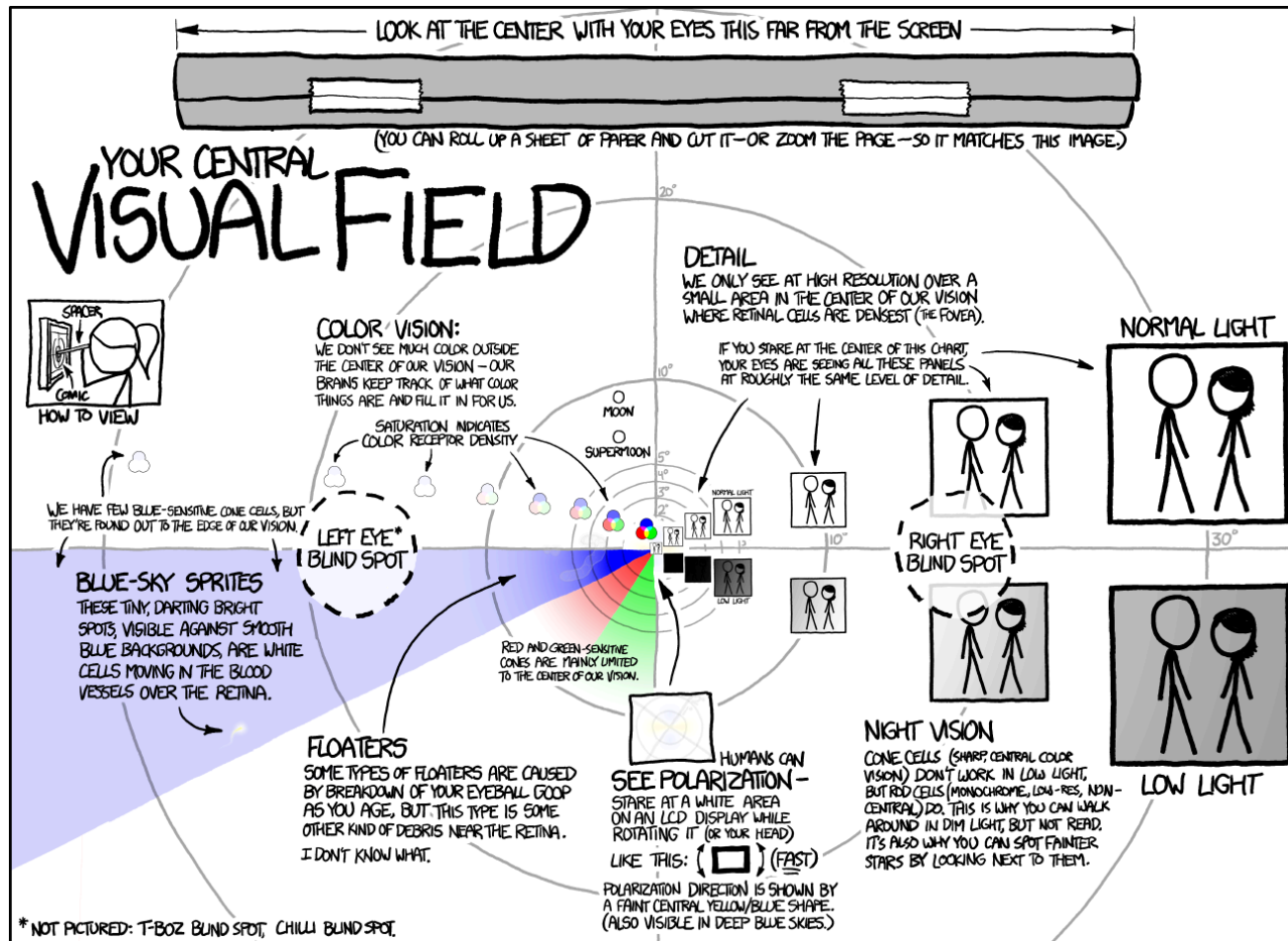
- Two types of light sensitive cells
  - **Rod Cells** (~120M)
    - Provide low-light vision
    - Peripheral vision
    - Almost no role in color vision
  - **Cone cells** (~6M)
    - Provide normal vision
    - Three sub-types of cells
      - Sensitivity to different light wavelengths
      - Used for colored vision



# Peripheral Vision Test – Game #1

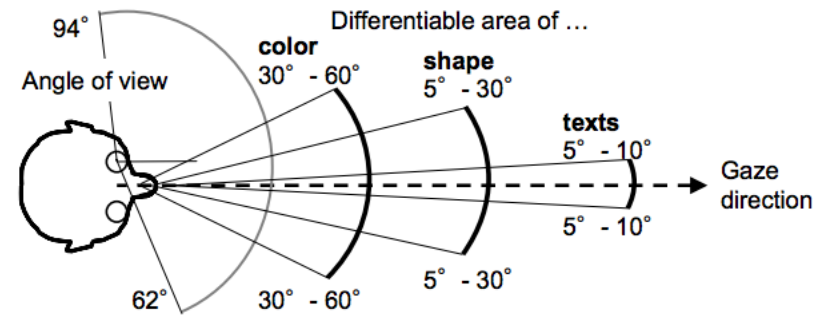


# Vision Resolution



# Vision Resolution

- Fovea yields the highest resolution (normal light)
- Fovea occupies around  $15^\circ$  of visual field
- Highest resolution is provided by *fovea centralis* (around  $1^\circ$ )



Komatsubara, A. Human error, Maruzen co. Ltd. 2008. (In japanese)

## THE GOBBLING GLUTTONS

ONCE UPON A TIME, WALDO EMBARKED UPON A FANTASTIC JOURNEY. FIRST, AMONG A THRONG OF GOBBLING GLUTTONS, HE MET WIZARD WHITEBEARD, WHO COMMANDED HIM TO FIND A SCROLL AND THEN TO FIND ANOTHER AT EVERY STAGE OF HIS JOURNEY. FOR WHEN HE HAD FOUND 12 SCROLLS, HE WOULD UNDERSTAND THE TRUTH ABOUT HIMSELF.

IN EVERY PICTURE FIND WALDO, WOOF (BUT ALL YOU CAN SEE IS HIS TAIL), WENDA, WIZARD WHITEBEARD, ODLAW, AND THE SCROLL. THEN FIND WALDO'S KEY, WOOF'S BONE (IN THIS SCENE IT'S THE BONE THAT'S NEAREST TO HIS TAIL), WENDA'S CAMERA, AND ODLAW'S BINOCULARS.

THERE ARE ALSO 25 WALDO-WATCHERS, EACH OF WHOM APPEARS ONLY ONCE SOMEWHERE IN THE FOLLOWING 12 PICTURES. AND ONE MORE THING! CAN YOU FIND ANOTHER CHARACTER, NOT SHOWN BELOW, WHO APPEARS ONCE IN EVERY PICTURE EXCEPT THE LAST?



## Where is Waldo? – Game #2



# High Resolution Vision

- HiRes vision is limited to a narrow angle of field vision
- Eyes move to scan an object in order to expose the image on the fovea
- The movement of eyes is not regular or linear

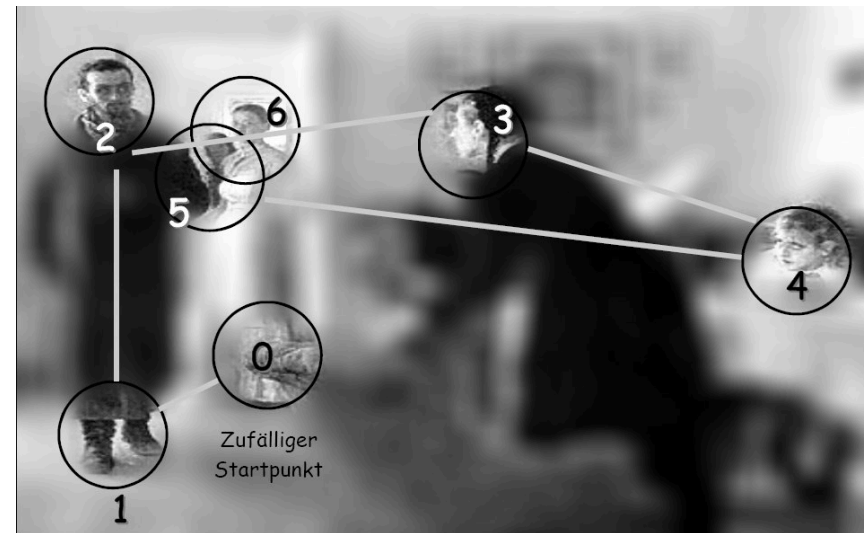


Bild 11: Foveale Ergänzung durch die ersten 6 Fixationen (nach Daten von *Yarbus, 1967*)

"Vision 2 secondes" by Hans-Werner Hunziker. Licensed under CC BY 3.0 via Wikimedia Commons - [http://commons.wikimedia.org/wiki/File:Vision\\_2\\_secondes.jpg#/media/File:Vision\\_2\\_secondes.jpg](http://commons.wikimedia.org/wiki/File:Vision_2_secondes.jpg#/media/File:Vision_2_secondes.jpg)

# Eye Tracking for Design



# Top-Down Attention



<http://channel.nationalgeographic.com/brain-games/videos/brain-games-pay-attention/>

# Perception and Cognition



VS



## Game #4 – How many 3s?

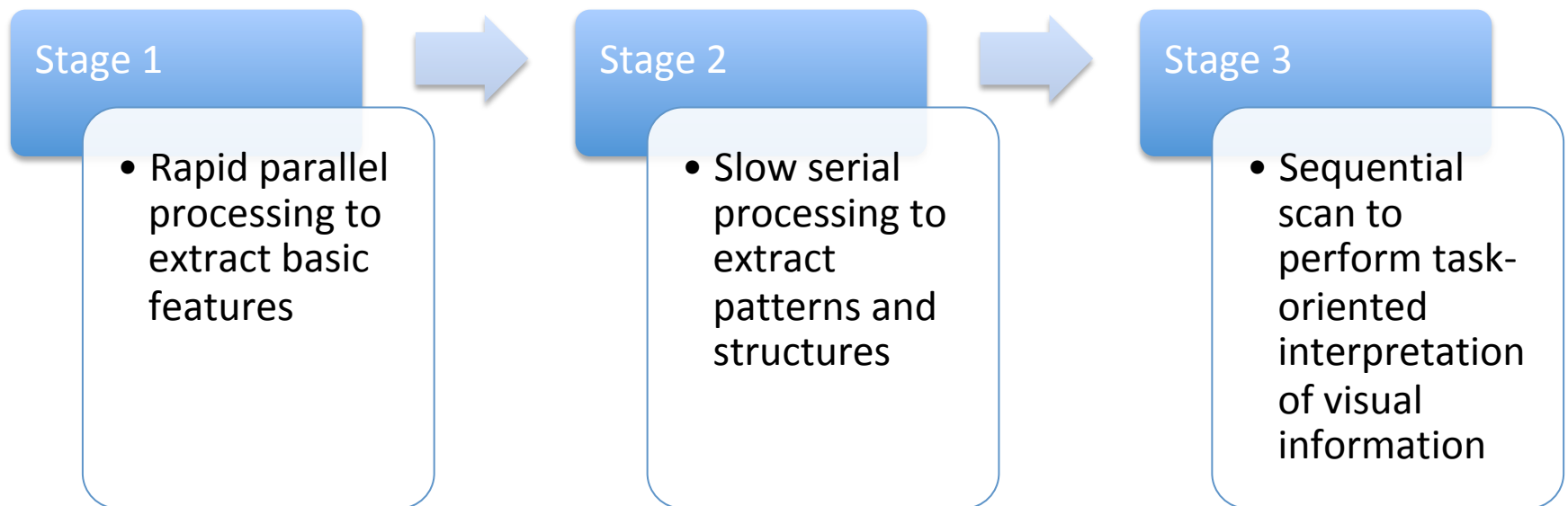
1258965168765132168943213  
5463479654321320354968413  
2068798417184529529287149  
2174953178195293926546831  
3546516509898554684982984

1258965168765132168943213  
5463479654321320354968413  
2068798417184529529287149  
2174953178195293926546831  
3546516509898554684982984

1258965168765132168943213  
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3546516509898554684982984

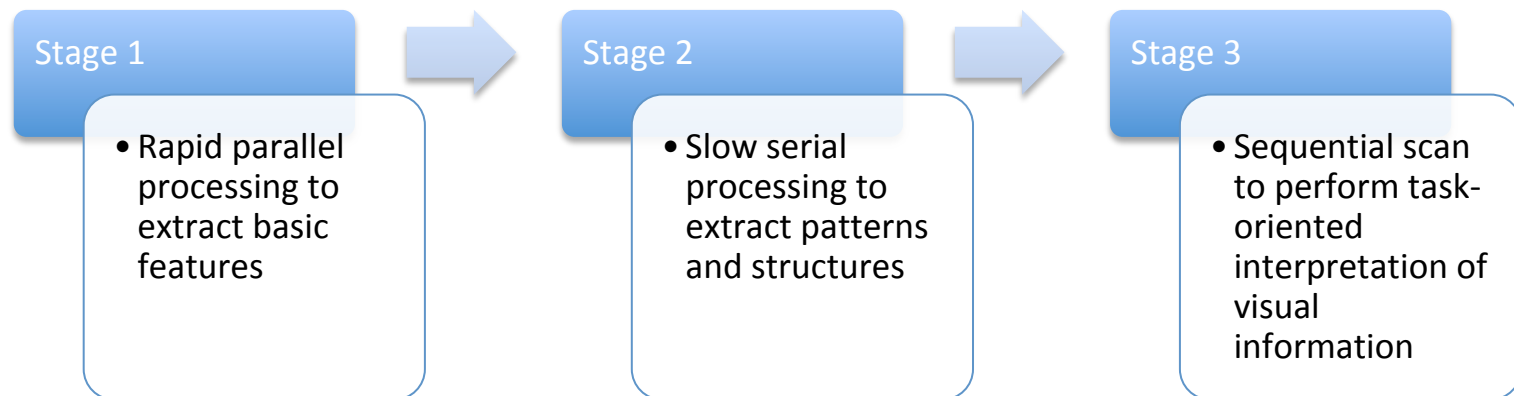
How many “3”?

# Perception and Cognition



# Visual Perception

- Early visual processing takes place without our conscious intervention
- Graphs that convey information at this level allow the observer to be more efficient in decoding



# Visual Cognition

- At second stage, the observer is required to consciously analyze the image/scene
- At this level, the observer can perform higher level reasoning
  - This object is larger than the other one
  - This street slope is lower than the previous



Timer

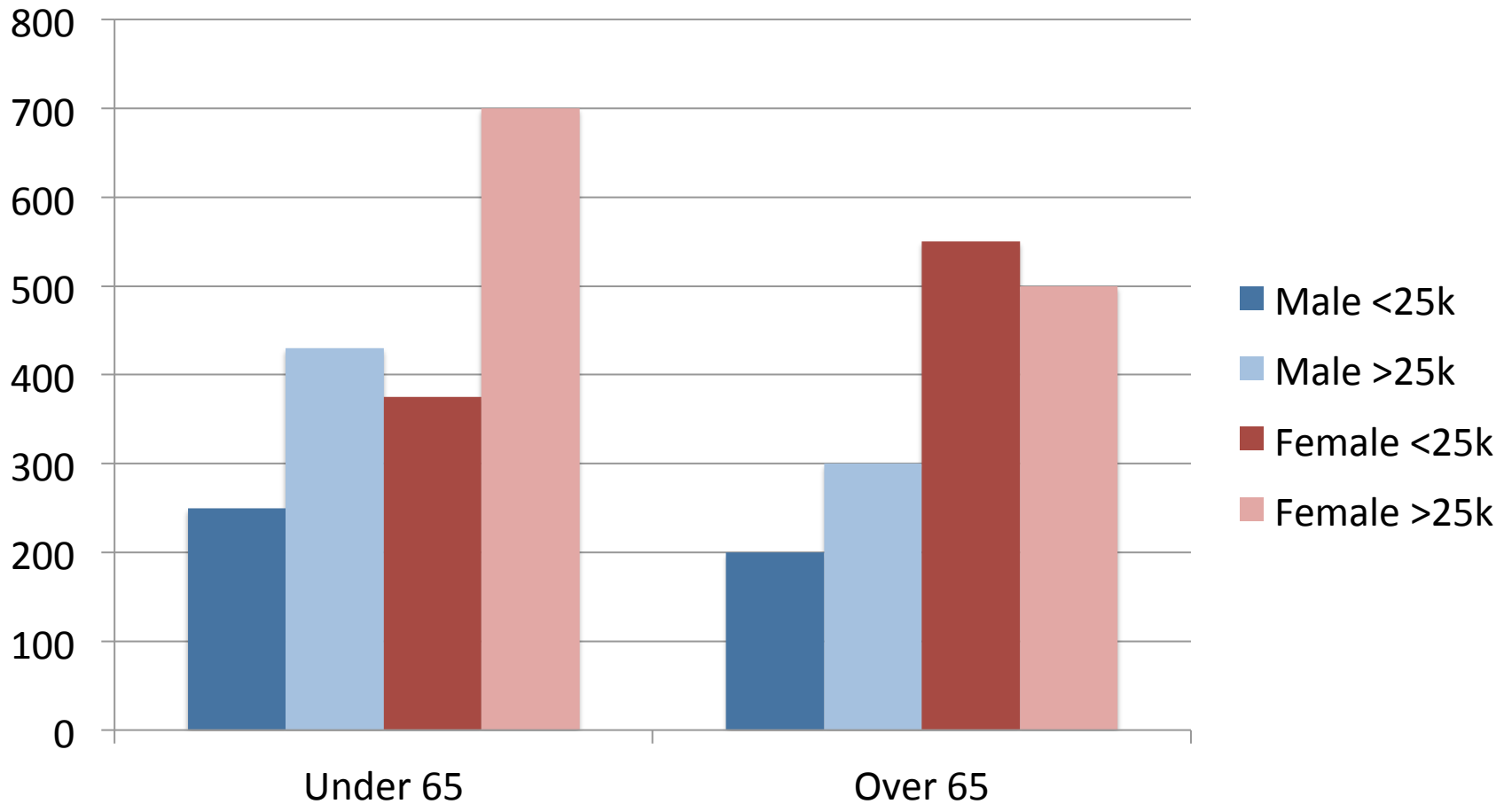
# **GAME #5 – CHOLESTEROL, AGE, AND GENDER**

## Game #5 – Cholesterol, Age, and Gender

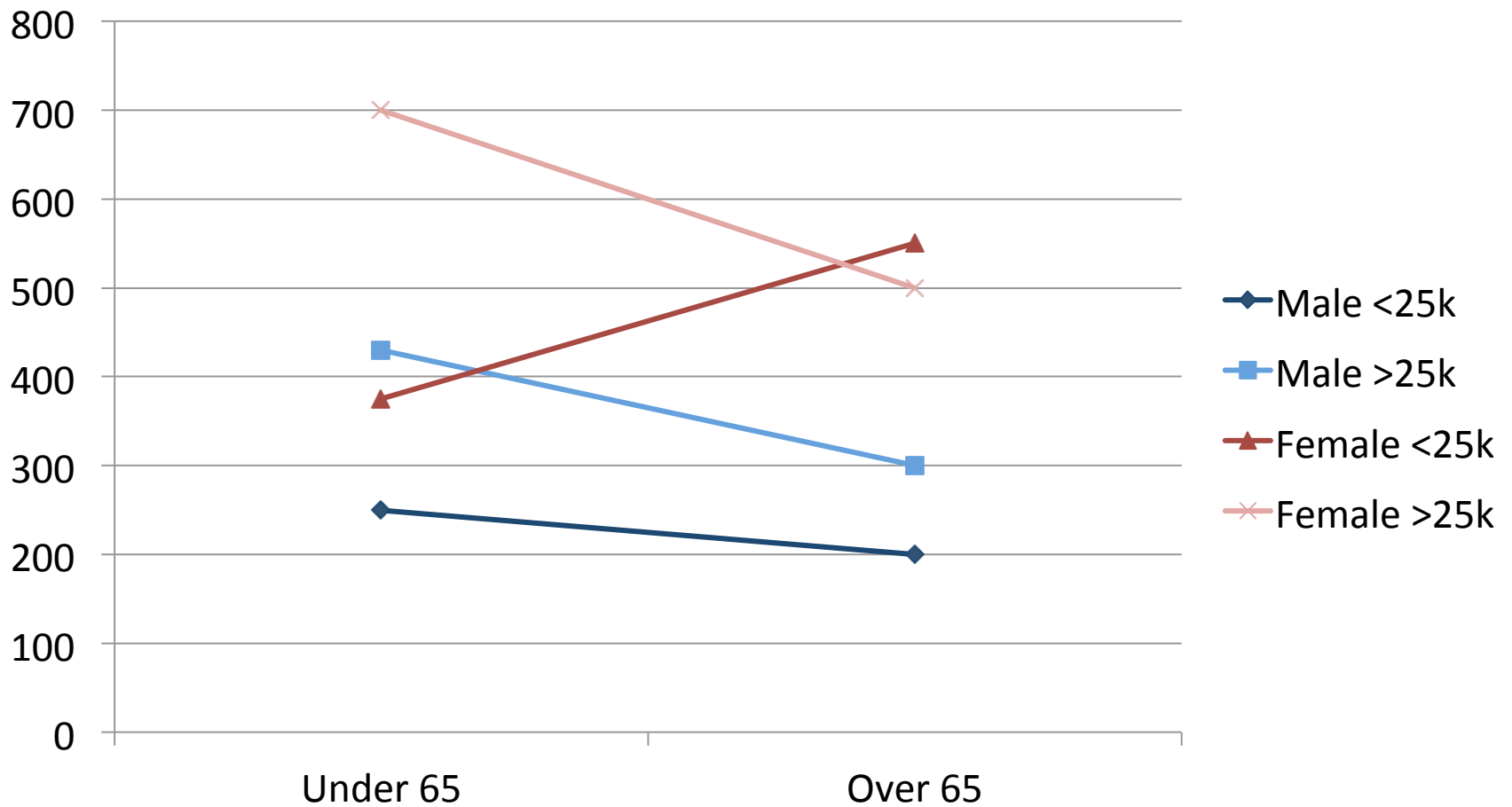
Which relation between gender or income level groups?

	Males		Females	
Income Group	Under 65	65 and Over	Under 65	65 and Over
0 – 24,999\$	250	200	375	550
25,000\$ +	430	300	700	500

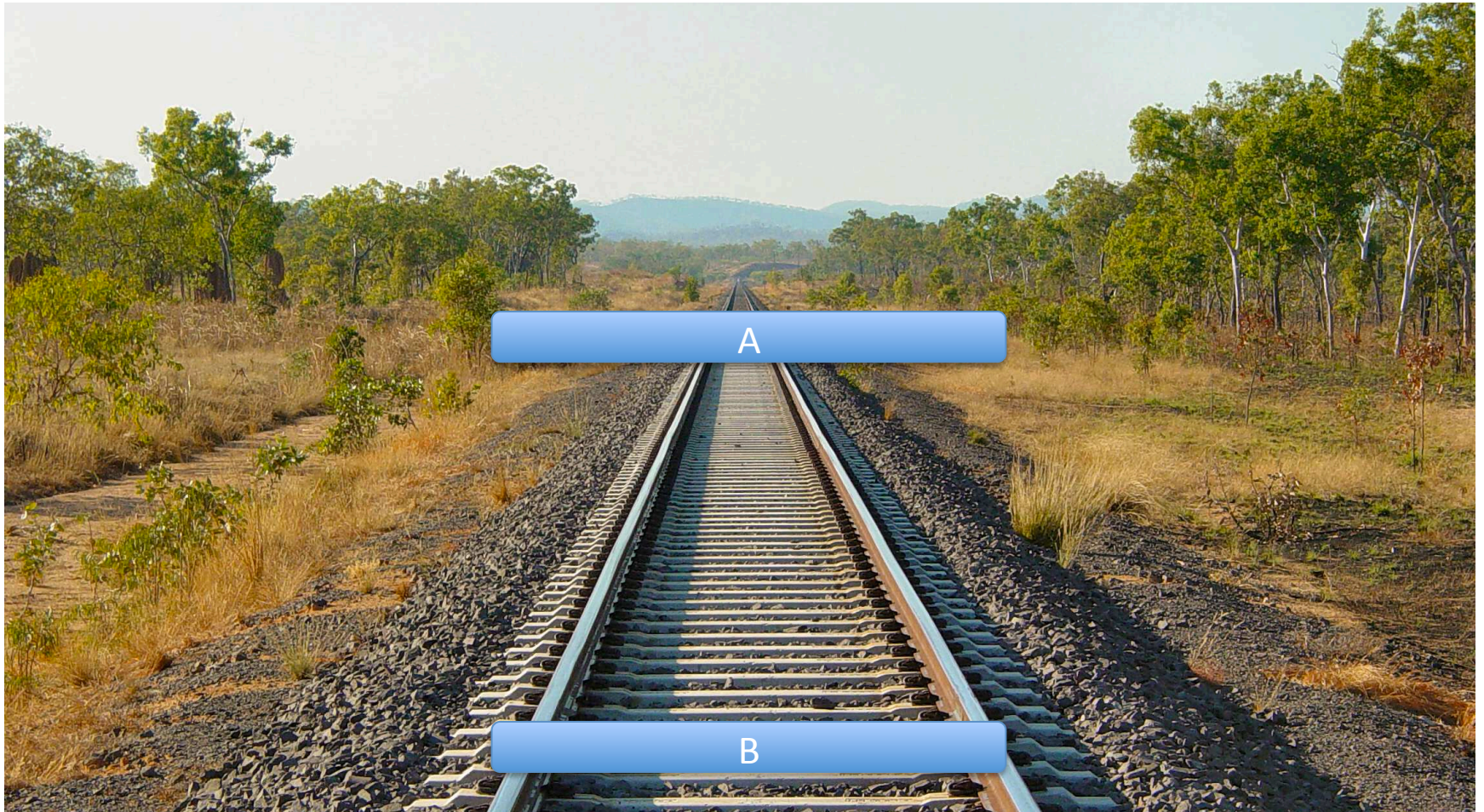
## Game #5 – Visual Solution (2)



## Game #5 – Visual Solution



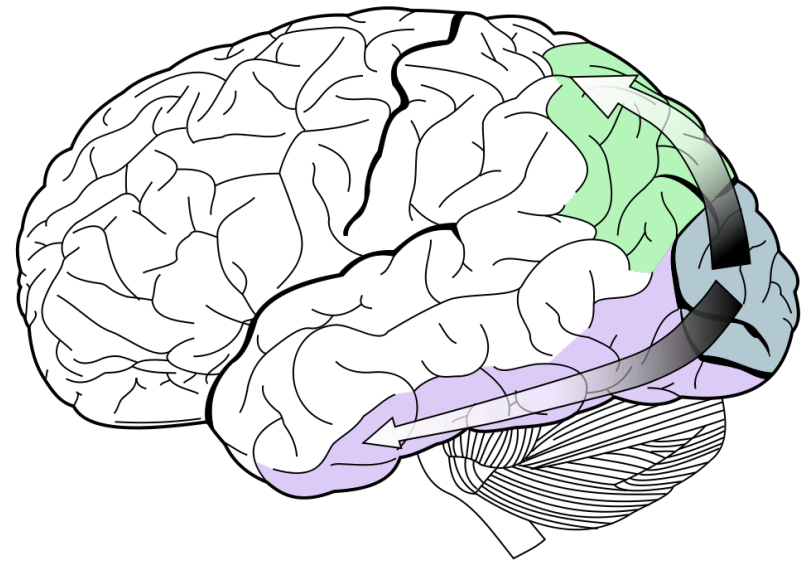
# Game #6 – Length comparison



# Perception

- Perception: the way in which something is regarded, understood, or interpreted (Oxford Dictionary)
- Electrical signals from vision system are interpreted and organized by the brain
- Two-stream hypothesis:
  - Ventral Stream
  - Dorsal Stream

The dorsal stream (green) and ventral stream (purple) are shown. They originate from a common source in the visual cortex

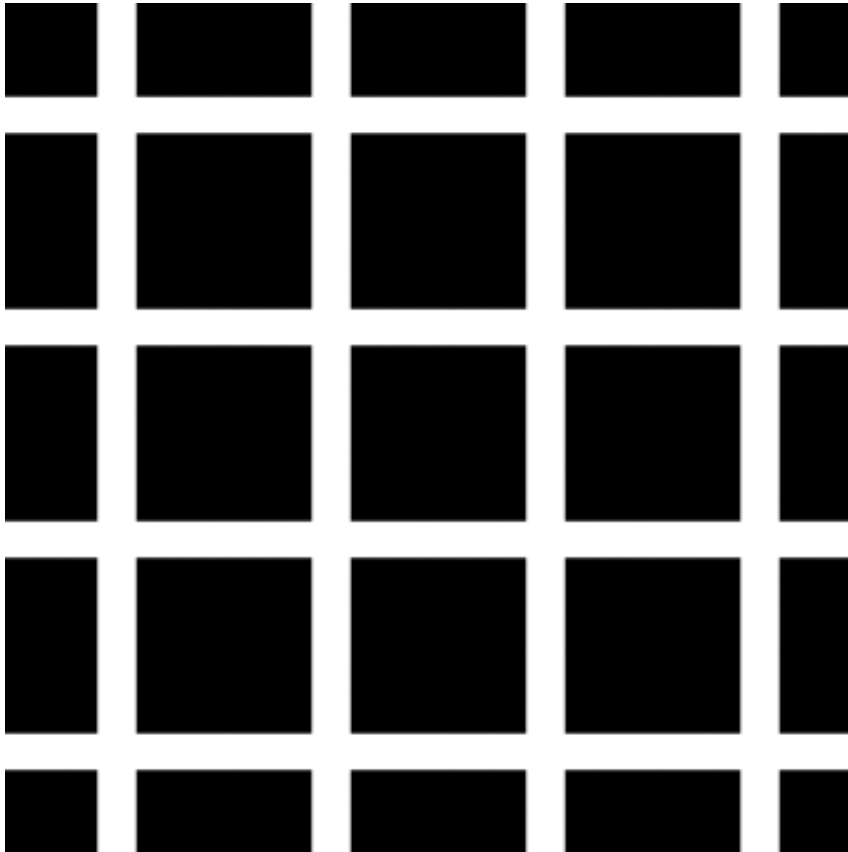


"Ventral-dorsal streams" by Selket - I (Selket) made this from Image:Gray728.svg. Licensed under CC BY-SA 3.0 via Wikimedia Commons - [http://commons.wikimedia.org/wiki/File:Ventral-dorsal\\_streams.svg#/media/File:Ventral-dorsal\\_streams.svg](http://commons.wikimedia.org/wiki/File:Ventral-dorsal_streams.svg#/media/File:Ventral-dorsal_streams.svg)

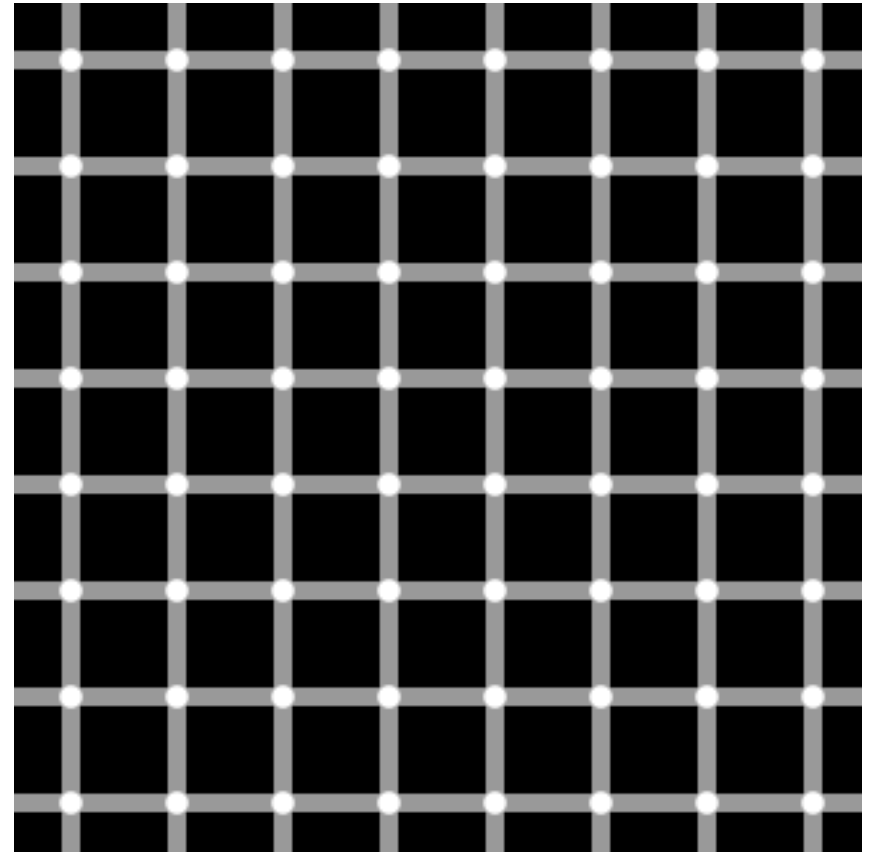
# Visual Illusions

- Perceived images differ from measurable reality
  - Optical Illusions
  - Physiological illusions (Mach Bands)
  - Cognitive illusions
    - Arise by unconscious inferences based on assumptions about real world

# Physiological Grid Illusion

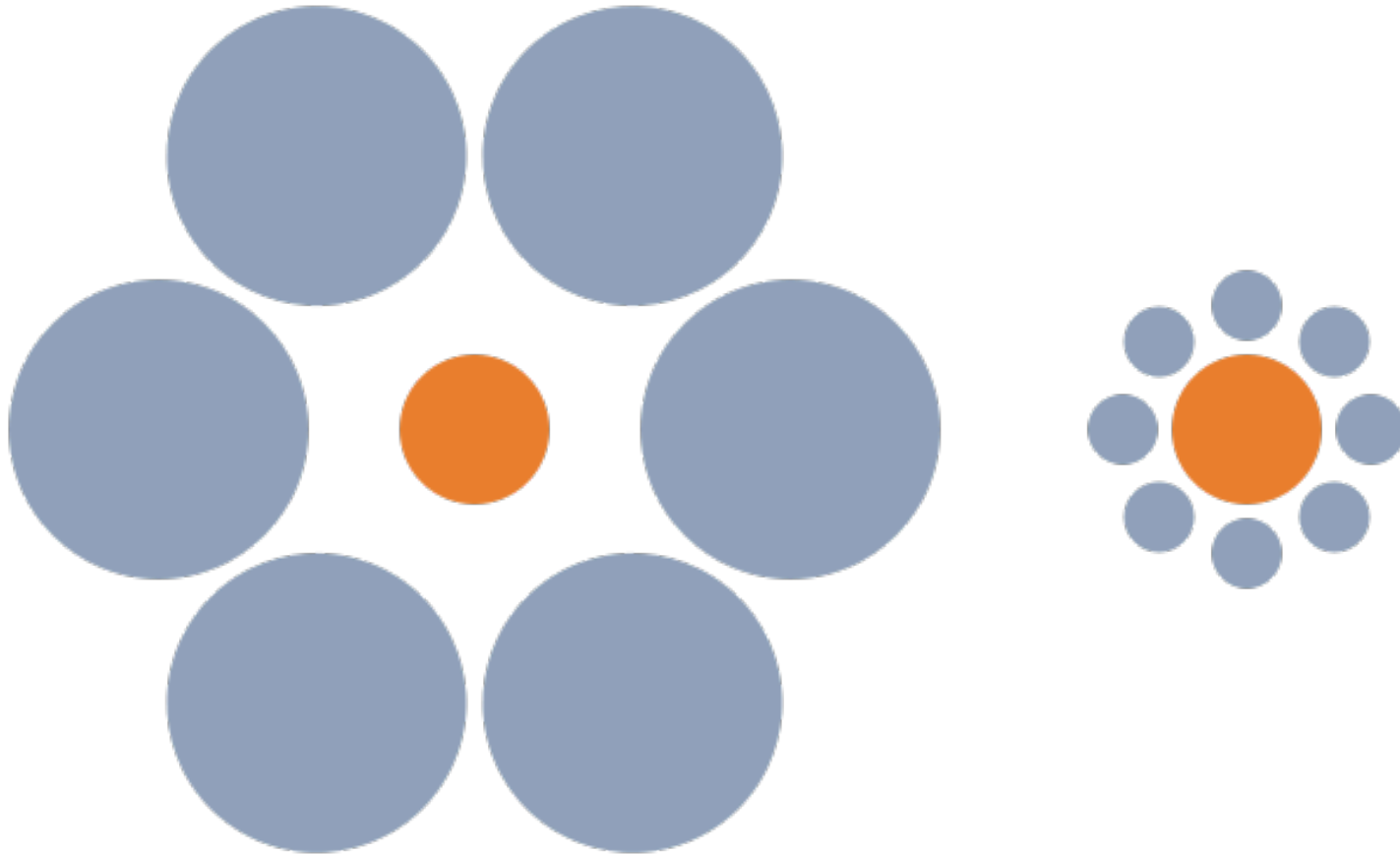


"HermannGrid" by en>User:Famousdog - <http://en.wikipedia.org/wiki/File:HermannGrid.gif>. Licensed under Public Domain via Wikimedia Commons - <http://commons.wikimedia.org/wiki/File:HermannGrid.gif#/media/File:HermannGrid.gif>



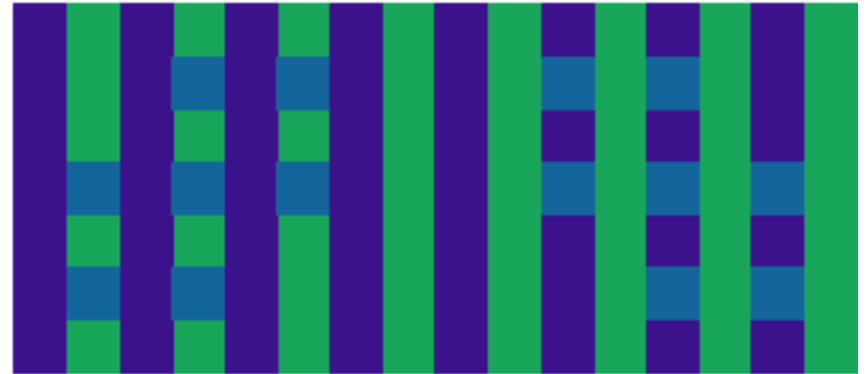
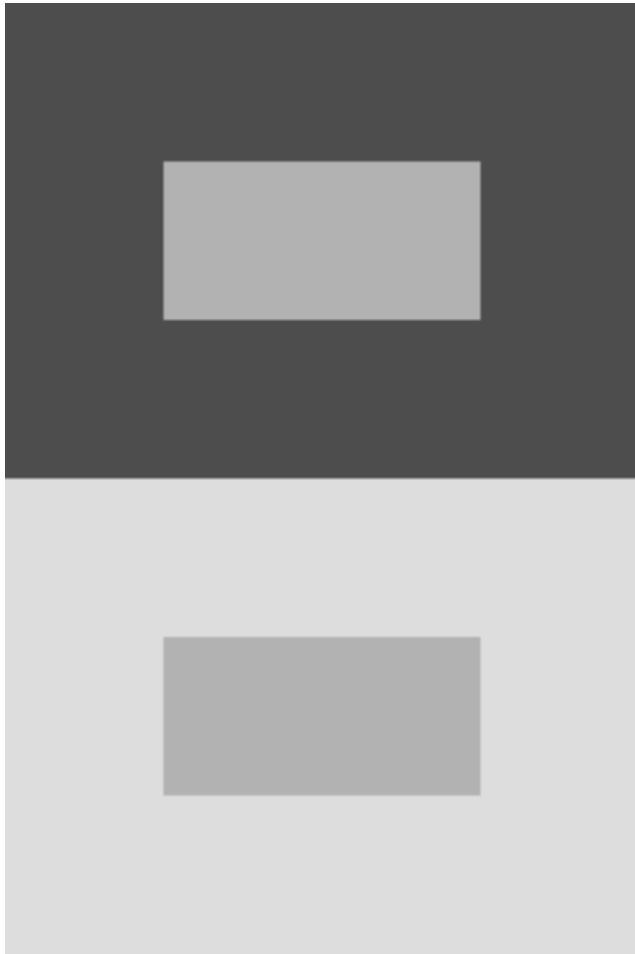
"Grid illusion" by User:Tó campos1 - Own work. Licensed under Public Domain via Wikimedia Commons - [http://commons.wikimedia.org/wiki/File:Grid\\_illusion.svg#/media/File:Grid\\_illusion.svg](http://commons.wikimedia.org/wiki/File:Grid_illusion.svg#/media/File:Grid_illusion.svg)

# Ebbinghaus Illusion



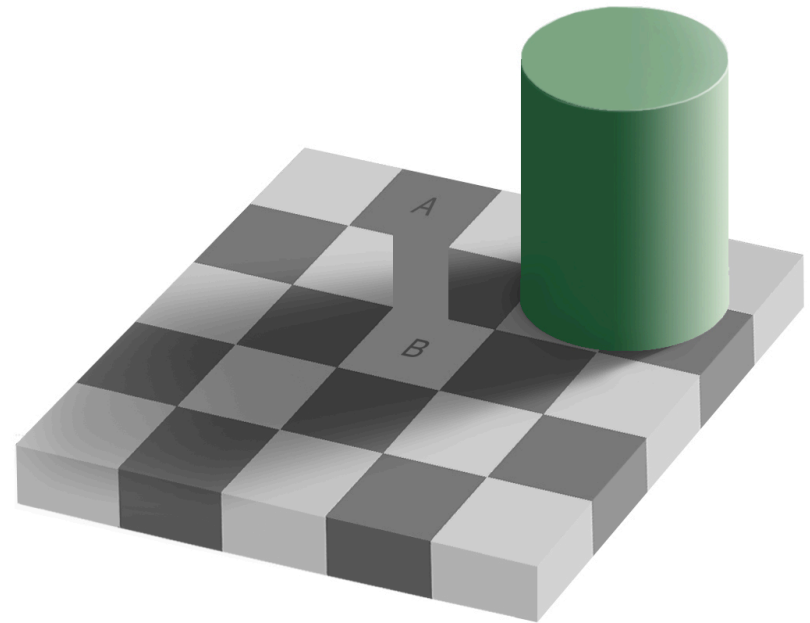
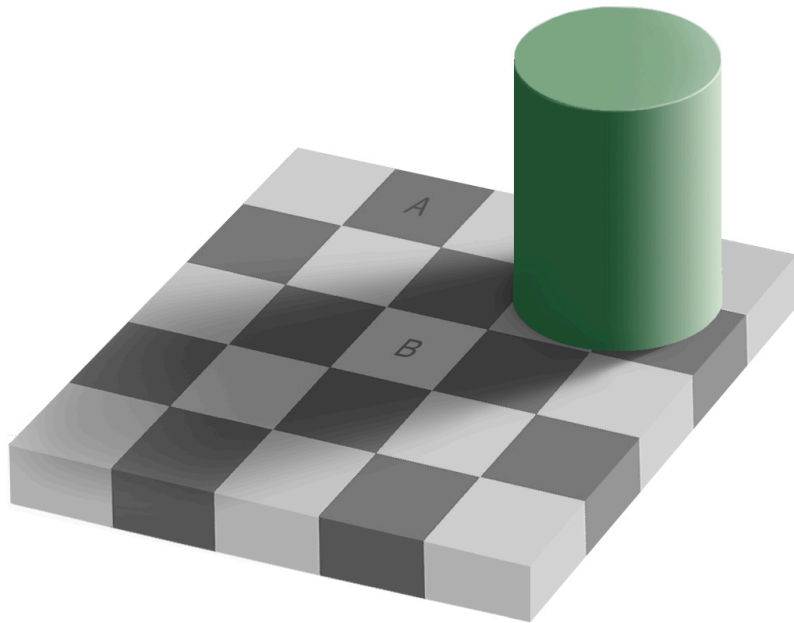
"Mond-vergleich". Licensed under Public Domain via Wikimedia Commons - <http://commons.wikimedia.org/wiki/File:Mond-vergleich.svg#/media/File:Mond-vergleich.svg>

# Simultaneous Contrast



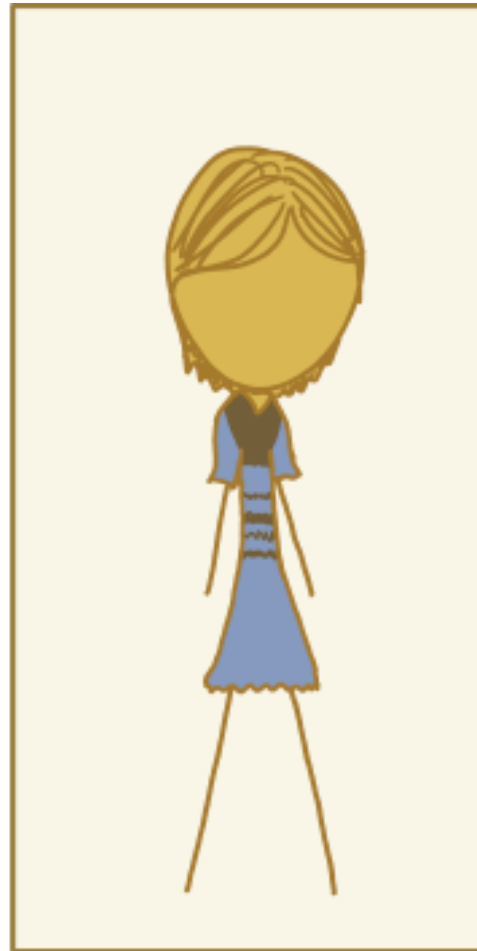
"Simultaneous Contrast" by K. P. Miyapuram - Licensed under Public Domain via Wikimedia Commons - [http://commons.wikimedia.org/wiki/File:Simultaneous\\_Contrast.svg#/media/File:Simultaneous\\_Contrast.svg](http://commons.wikimedia.org/wiki/File:Simultaneous_Contrast.svg#/media/File:Simultaneous_Contrast.svg)

# Adelson's Illusion



"Grey square optical illusion" by Original by Edward H. Adelson, this file by Gustavb - File created by Adrian Pingstone, based on the original created by Edward H. Adelson. Licensed under Copyrighted free use via Wikimedia Commons - [http://commons.wikimedia.org/wiki/File:Grey\\_square\\_optical\\_illusion.PNG#/media/File:Grey\\_square\\_optical\\_illusion.PNG](http://commons.wikimedia.org/wiki/File:Grey_square_optical_illusion.PNG#/media/File:Grey_square_optical_illusion.PNG)

# Dress Color



# Takeaway Messages

- Limitations of human vision system
- Exploits message broadcast at early stage of perception: preattemptive perception
- Avoid possible causes of biases



# **VISUAL VARIABLES**

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# SCIENCE

Vol. 103, No. 2684

Friday, June 7, 1946

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## On the Theory of Scales of Measurement

S. S. Stevens

*Director, Psycho-Acoustic Laboratory, Harvard University*

FOR SEVEN YEARS A COMMITTEE of the British Association for the Advancement of Science debated the problem of measurement. Appointed in 1932 to represent Section A (Mathematical and Physical Sciences) and Section J (Psychology), the committee was instructed to consider and report upon the possibility of "quantitative estimates of sensory events"—meaning simply: Is it possible to measure human sensation? Deliberation led only to disagreement, mainly about what is meant by the term measurement. An interim report in 1938 found one member complaining that his colleagues

by the formal (mathematical) properties of the scales. Furthermore—and this is of great concern to several of the sciences—the statistical manipulations that can legitimately be applied to empirical data depend upon the type of scale against which the data are ordered.

### A CLASSIFICATION OF SCALES OF MEASUREMENT

Paraphrasing N. R. Campbell (Final Report, p. 340), we may say that measurement, in the broadest sense, is defined as the assignment of numerals to objects or events according to rules. The fact that numerals can be assigned under different rules leads

# Data Types

- Nominal (N)
  - Equality relation
  - Apples, bananas, pears,...
- Ordinal (O)
  - Ordering relation
  - Small, medium, large, darker, dark, light,...
- Quantitative (Q)
  - Arithmetic relations
  - 10m, 32 degree, 2 bars,...
- Q-Interval (no reference point)
  - Dates, Location
  - Not directly comparable
  - Distances: A is 3 degree hotter than B
- Q-Ratio (reference point)
  - Length, mass
  - Proportions: A is twice as large as B

# Data Types Operators

- Nominal
  - $\neq, =$
- Ordinal
  - $\neq, =, >, <$
- Quantitative Interval
  - $\neq, =, >, <, +, -$
- Quantitative Ratio
  - $\neq, =, >, <, +, -, \times, \div$

# From Data to Conceptual Model

- Data Model: low-level representation of data and operations
- Conceptual Model: mental and semantic construction

Data	Concept
1D number	Temperature
2D numbers	Geographic Coordinate
3D numbers	Spatio-temporal position

# From Data to Conceptual Model

- From data model...
  - 70.8, 27.2, -10.2,...
- ... using conceptual model ...
  - Temperature
- ... to data type
  - Continuous variation
  - Warm, hot, cold
  - Burned vs not burned

# Visual Variables

- Jacques Bertin (1918-2010), cartographer
- Theoretical principles of visual encodings
- Semiology of Graphics (1967)



[Graphics] is a strict and simple system of signs, which anyone can learn to use and which leads to better understanding.

— Jacques Bertin —

AZ QUOTES

# Bertin's Visual Variables

## Variables of a Visual Image

X Y  
2 Dimensions  
of A Chart

Z

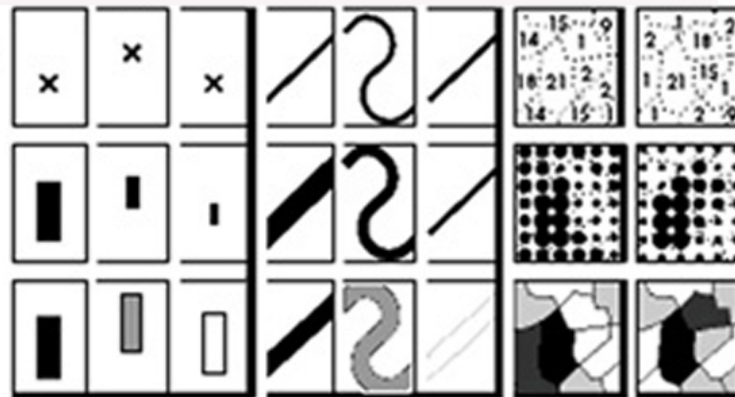
Size

Value

Points

Lines

Areas



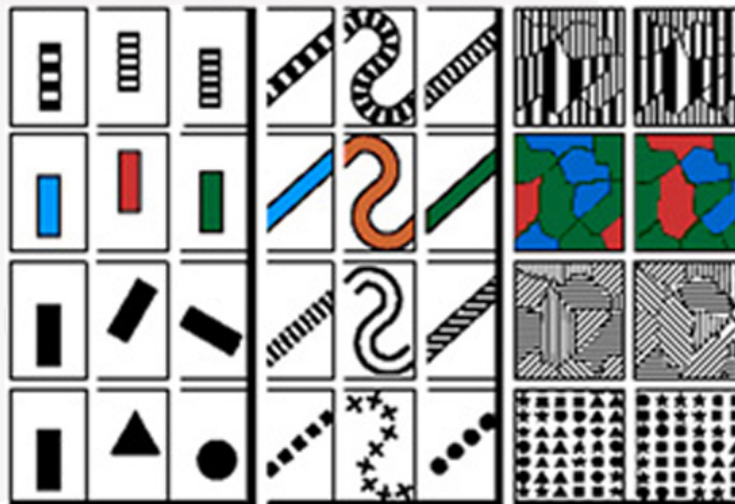
## Variables to Separate Images

Texture

Colour

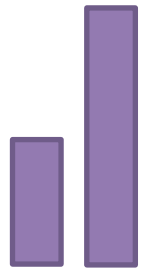
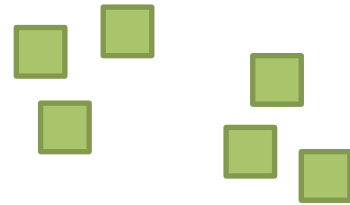
Orientation

Shape



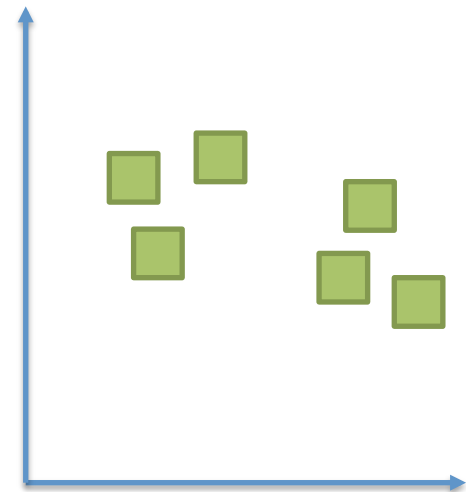
# Characteristics of Visual Variables

- Selective
  - May I distinguish a symbol from the others
- Associative
  - May I identify groups?
- Quantitative
  - May I quantify the difference of two values?
- Order
  - May I identify an ordering?
- Length
  - How many values?



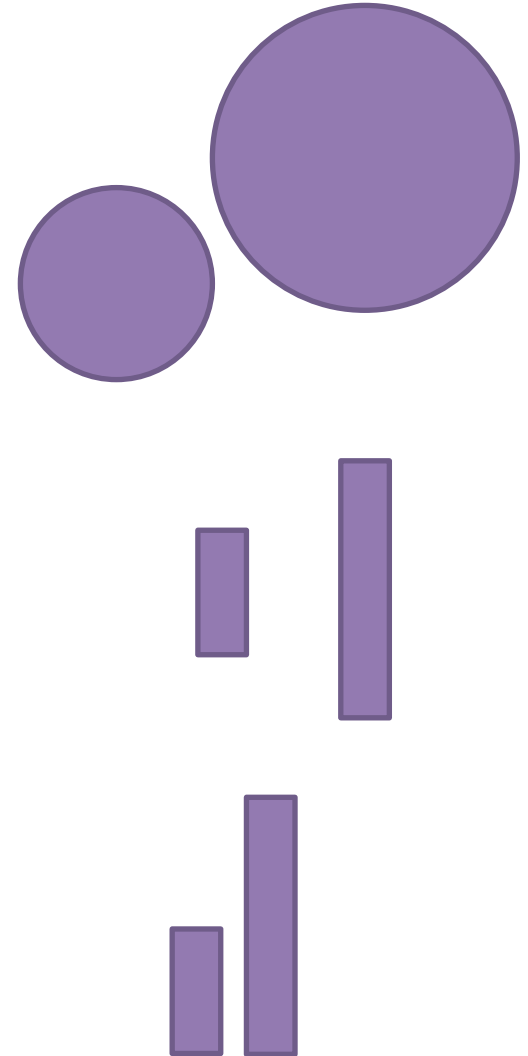
# VV: Position

- Strongest visual variable
- Compatible for all data types
- Cons:
  - Not always applicable (e.g. nD data)
  - Cluttering



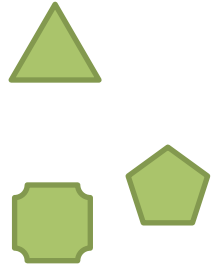
# VV: Size and Length

- Easy to compare dimensions
- Grouping
- Estimate differences
  - Quantitative encoding
  - Changes in lengths
  - Worse for change in area



## VV: Shapes

- Strong for nominal encoding
- No ordering
- No grouping



## VV: Value (intensity)

- Quantitative representation (when size and length are used)
- Limited number of shades
- Support grouping



## VV: Color (Tint)

- Good for qualitative data
- Limited number of classes (!!!)
- Not good for quantitative data
- Be careful!!

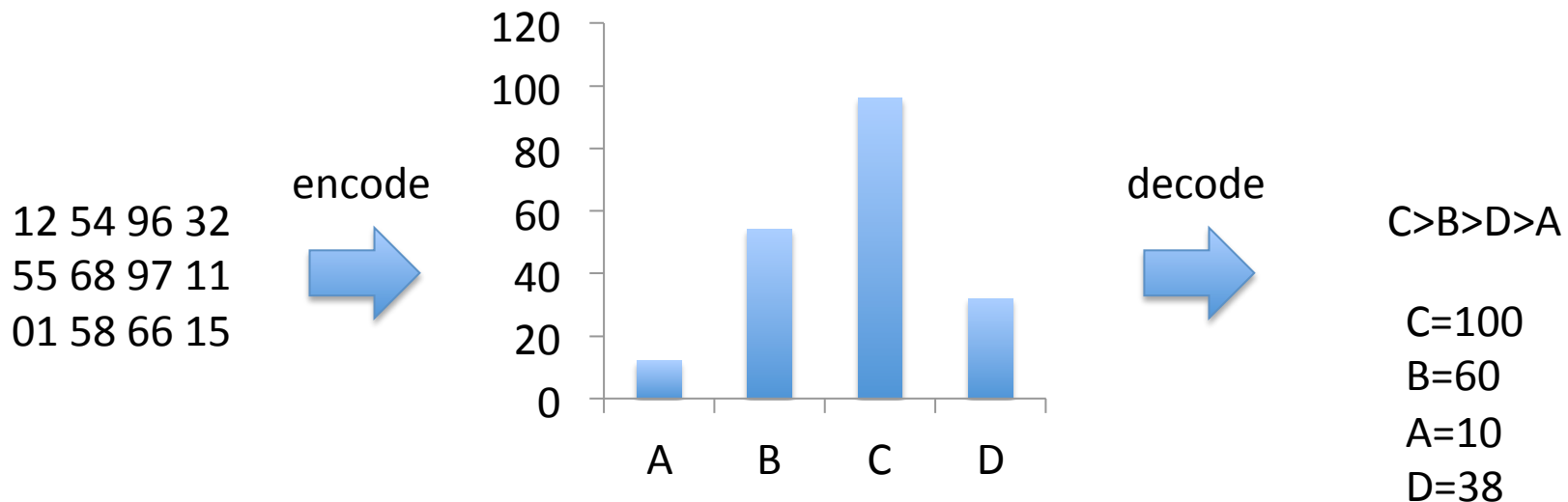


# Bertin Visual Variables

	Nominal	Ordinal	Quantitative
Position	✓	✓	✓
Size	✓	✓	~
Value (intensity)	✓	✓	~
Texture	✓	~	✗
Color	✓	✗	✗
Orientation	✓	✗	✗
Shape	✓	✗	✗

# Visual Encoding/Decoding

- A graph **encode** a set of information as a set of graphical attributes
- The observer have to **decode** the graphical attributes to extract the original information





# **TAXONOMY OF VISUAL VARIABLES**

# Cleveland McGill [1984]

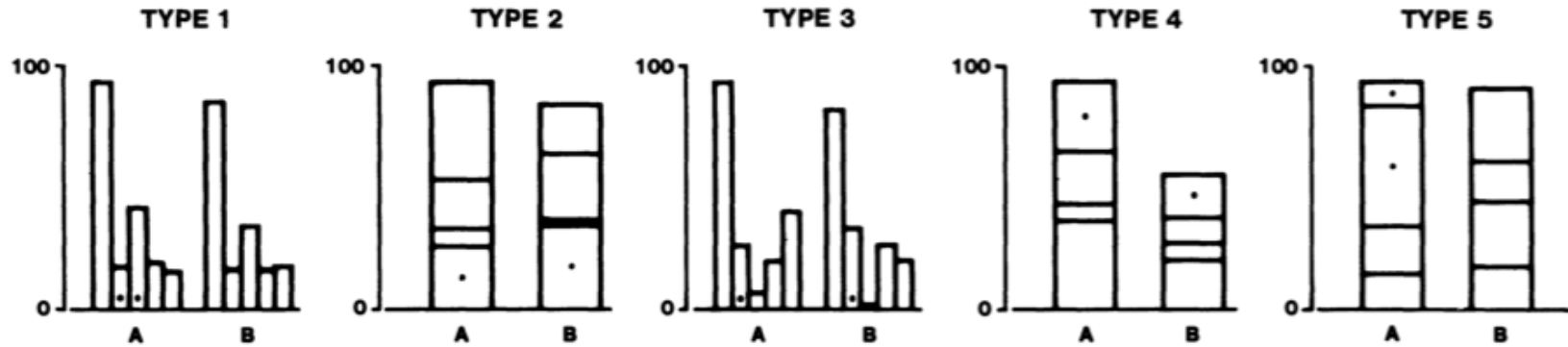


Figure 4. Graphs from position-length experiment.

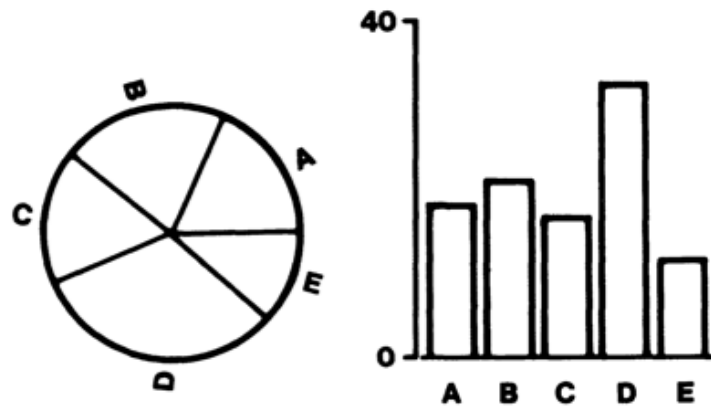
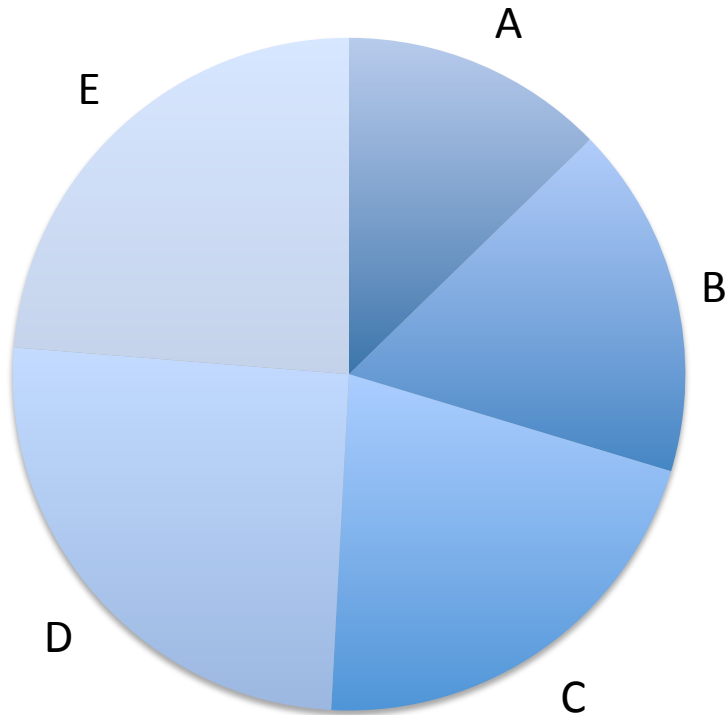


Figure 3. Graphs from position-angle experiment.

# Cleveland & McGill: graphical encodings

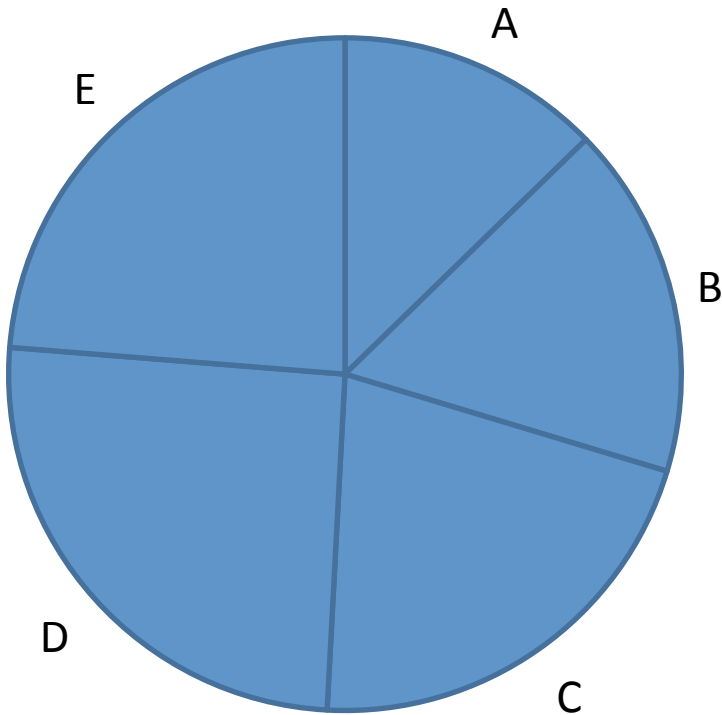
- Angle
- Area
- Color Hue
- Color Saturation
- Density
- Length
- Position on a common scale
- Position on non aligned scale
- Slope
- Volume

# Angle decoding



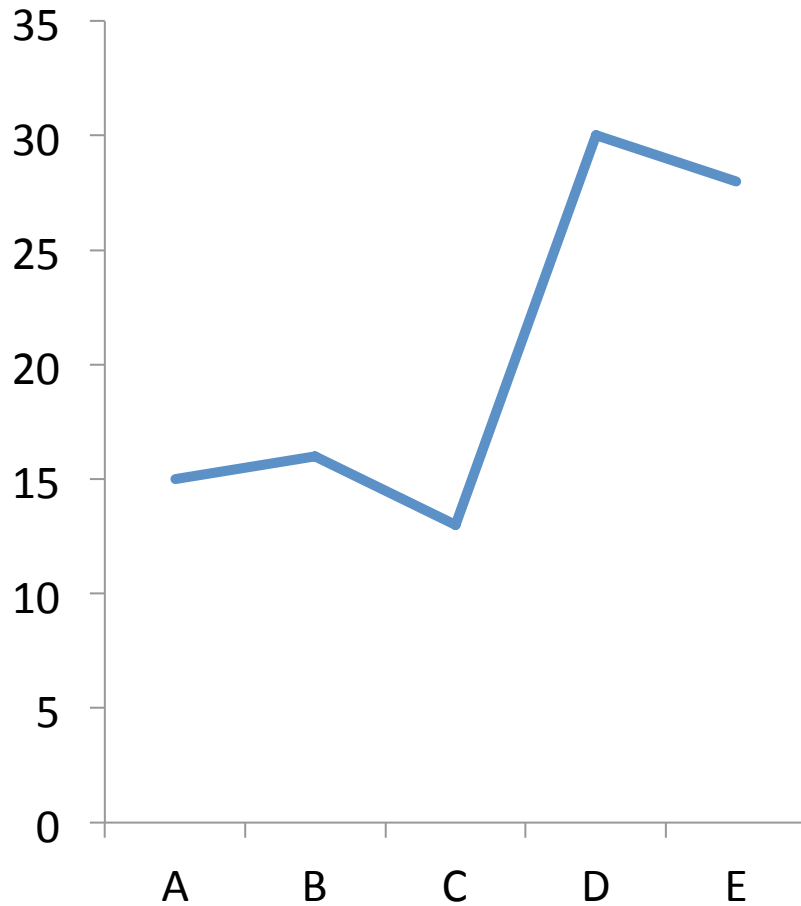
- It is difficult to compare angles
  - Underestimation of acute angles
  - Overestimation of obtuse angles
  - Easier if bisectors are aligned
- Area estimation helps

# Angle decoding



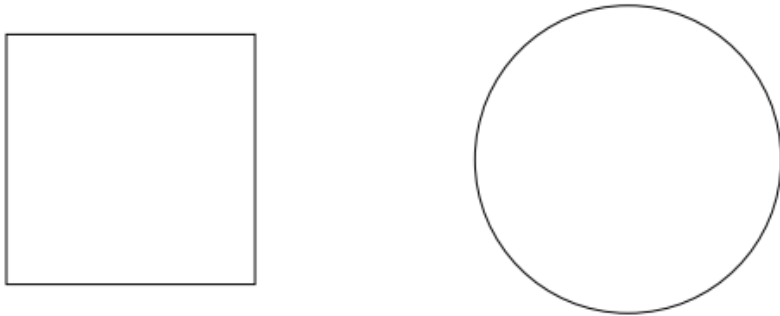
- It is difficult to compare angles
  - Underestimation of acute angles
  - Overestimation of obtuse angles
  - Easier if bisectors are aligned

# Slopes Decoding



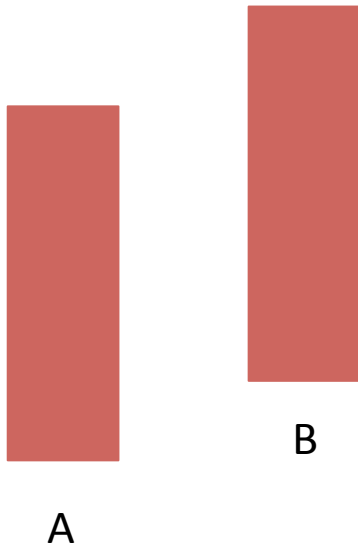
- Same difficulties as angles
- Easier task since one branch is aligned with x-axis

# Area Decoding



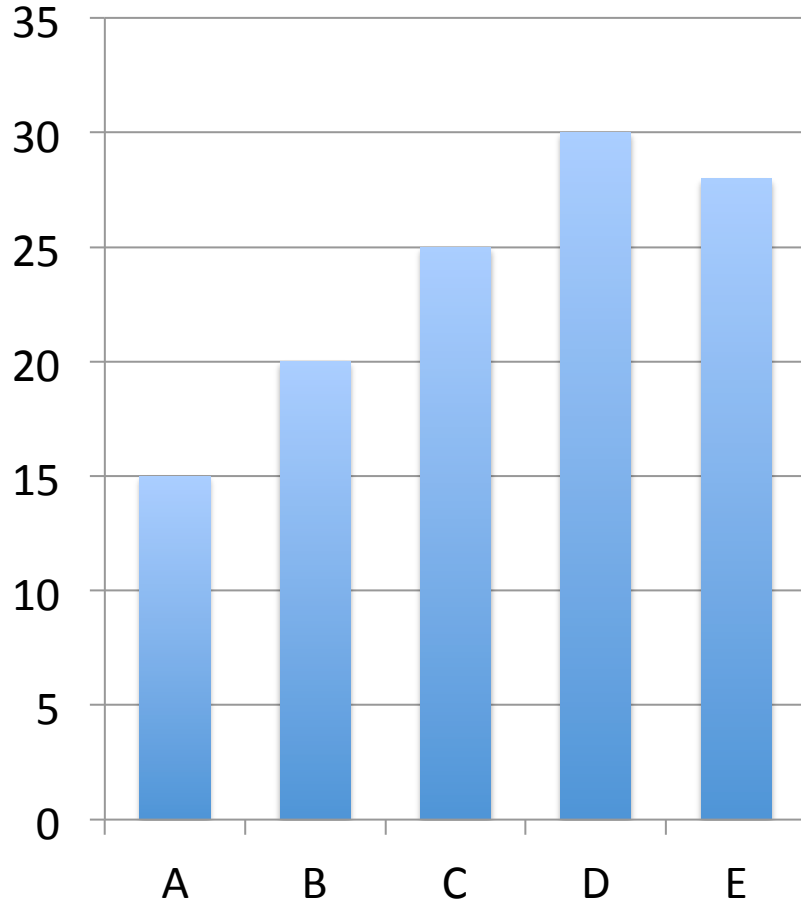
- Area is not well decoded
  - Different regular shapes
  - Irregular shapes
  - Context influences (thin area within compact thick area)

# Length Decoding



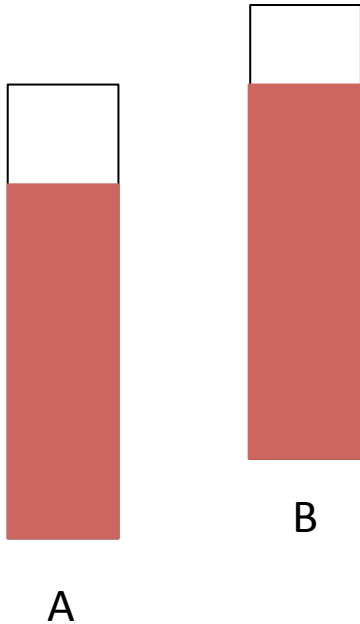
- Straight forward to encode numerical values
- Difficulties with relative lengths

# Position on a common scale



- Widely used in statistical charts

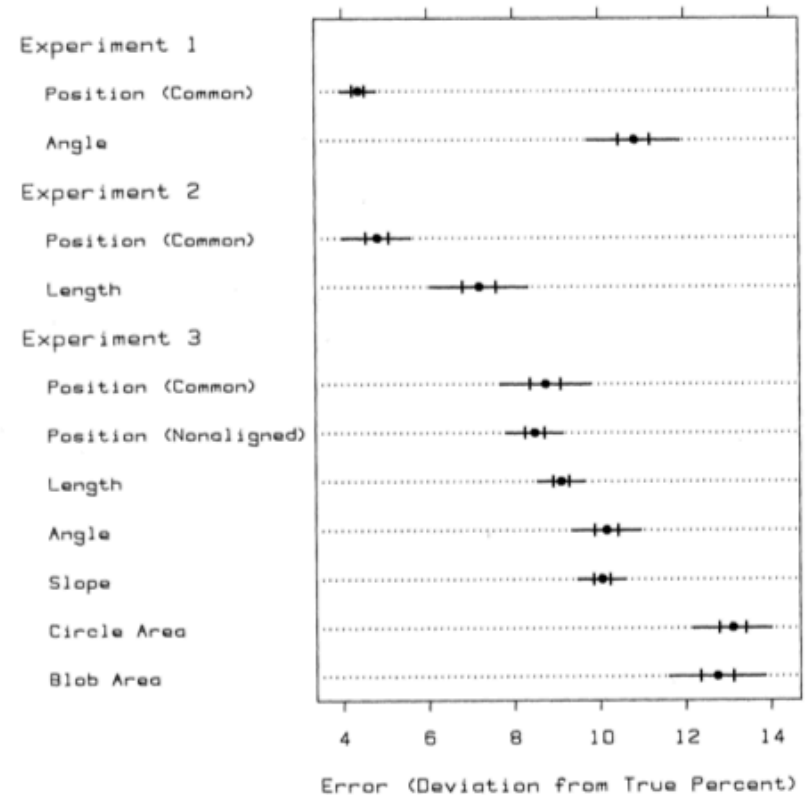
# Position on non-aligned scale



- Not as bad as common scale
- Still acceptable

# Designing Effective Visualizations

- If possible, use graphical encoding that are easily decoded
- Graphical Attributes ordered (Cleveland & McGill):
  - Position along a common scale
  - Position on non aligned scales
  - Length
  - Angle and Slope
  - Area
  - Volume, density, color saturation
  - Color Hue





Most  
Efficient



Least  
Efficient

Position



Length



Slope



Angle



Area



Intensity



Color



Shape



Quantitative

Ordinal

Nominal



# **PERCEPTION LAWS**

# Weber's Law

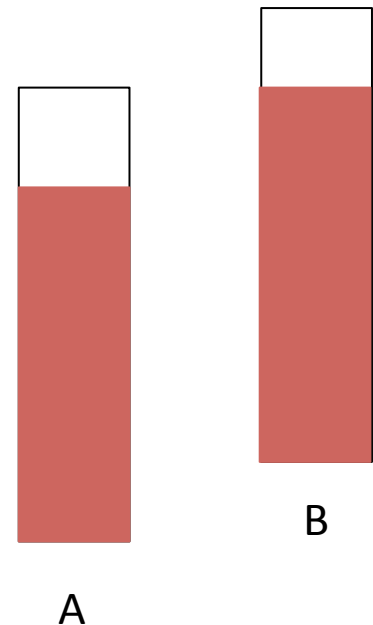
- Just-noticeable difference between two stimuli is proportional to their magnitudes
- Case study on length
  - Given two lines with lengths  $x$  and  $x+w$
  - If  $w$  is small, it is difficult to notice difference between the two lines
  - If  $w$  is larger, it is easier to catch the difference
- How large should  $w$  be?
  - The probability of detecting the change is proportional to the relative value  $w/x$

# Weber's Law

- Given values (90, 92)
- Detect with probability of  $2/90$



- Given values (90, 92)
- Detect with probability of  $2/10$

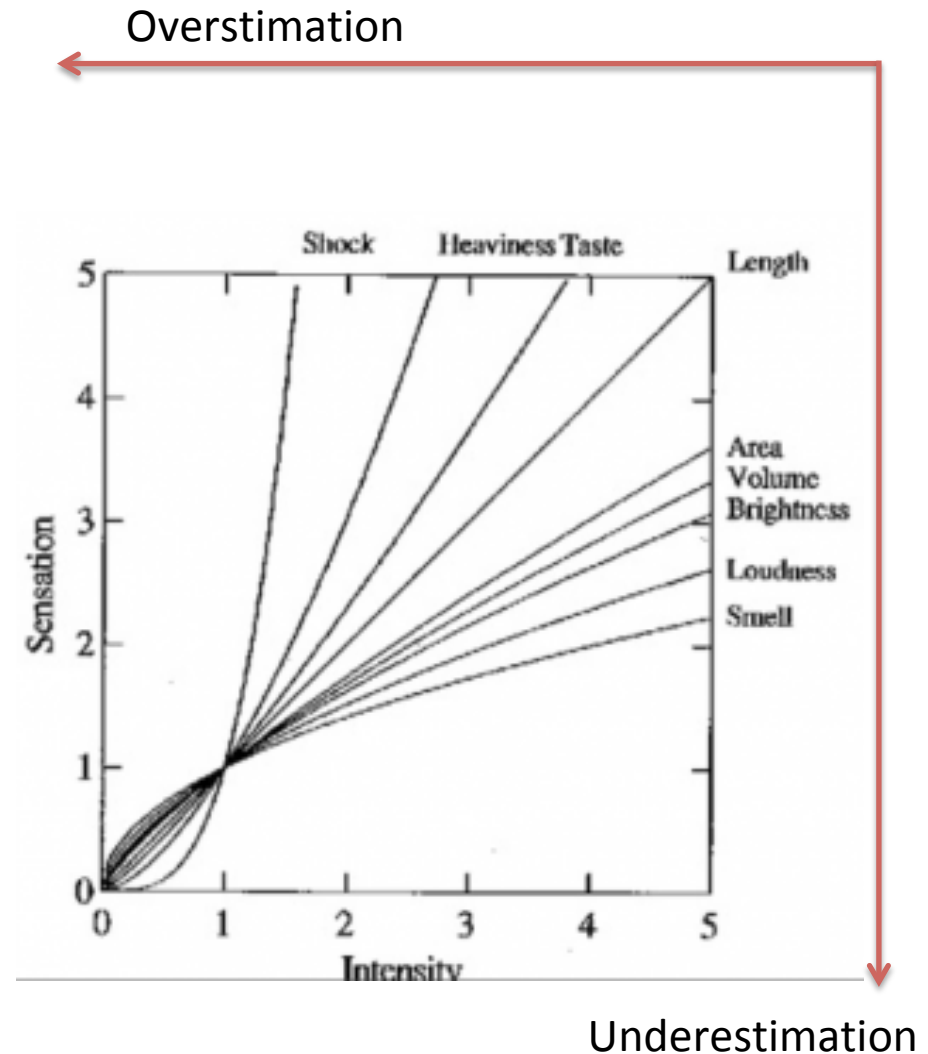


# Stevens' Law

- Model the relation between a stimulus and its perceived intensity
- Given a stimulus  $x$  encoded with a visual attribute
- An observer decode a perceived value  $p(x)$
- Stevens' law states that
  - $p(x) = kx^\beta$
  - where  $k$  is constant and
  - $\beta$  is a constant that depends on the nature of stimulus

# Stevens' law

- Better effectiveness when  $p(x) = kx^\beta$  is linear
- Linearity depends only on  $\beta$
- Different visual encodings yields typical ranges for  $\beta$ 
  - Lengths: 0.9 – 1.1
  - Area: 0.6 – 0.9
  - Volume: 0.5 – 0.8



# Weber and Stevens' Laws

- Given two values  $x_1$  and  $x_2$
- Let the perceived values be  $p(x_1)$  and  $p(x_2)$

$$\frac{p(x_1)}{p(x_2)} = \left( \frac{x_1}{x_2} \right)^\beta$$

# Weber and Stevens' Laws: areas

- For areas  $\beta=0.7$
- Let  $x_1=2$  and  $x_2=1$
- The perceived difference will be

$$\frac{p(2)}{p(1)} = \left(\frac{2}{1}\right)^{0.7} = 1,6245$$

- For areas  $\beta=0.7$
- Let  $x_1=0,5$  and  $x_2=1$
- The perceived difference will be

$$\frac{p(\frac{1}{2})}{p(1)} = \left(\frac{1/2}{1}\right)^{0.7} = 0,6155$$

# Weber and Stevens' Laws: areas vs lengths

- For areas  $\beta=0.7$

- Let  $x_2=x_1+w$

- The perceived difference will be

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

- For lengths  $\beta=1$

- Let  $x_2=x_1+w$

- The perceived difference will be

$$\left(\frac{x+w}{x}\right)^1 = 1 + \frac{w}{x}$$

## Takeaway messages

- Data type for entities and relationships
- Visual variables for representation
- Mapping of types to VVs
- Some VVs are more appropriate for specific data types