Information Visualization and Visual Analytics (M1522.000500)

Marks and Channels

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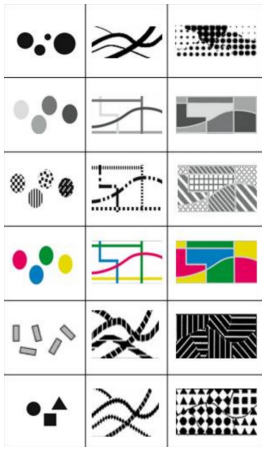
Why Marks and Channels?

- Every complex visual encoding **idiom** can be broken down **into** two orthogonal **components** : Marks and Channels

Idiom

Marks & Channels



Marks

- Basic graphical element
- Classified with their spatial dimension
  - Point (0D), Line (1D), Area (2D), Volume (3D)

Points **Lines** **Areas**

Marks and Their Types

- Geometric primitives

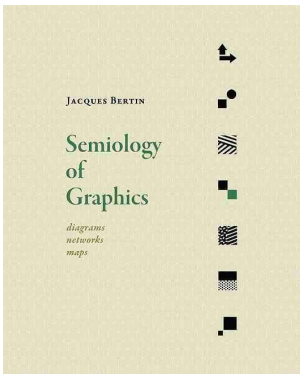
Marks as Items/Nodes

Points **Lines** **Areas**

Marks as Links

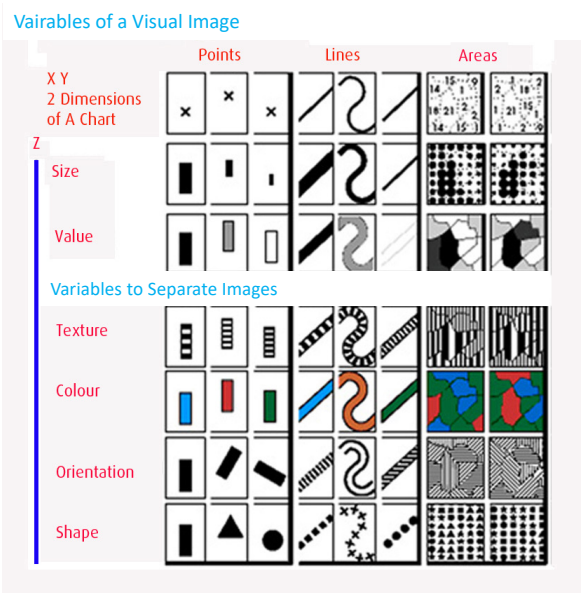
Containment **Connection**

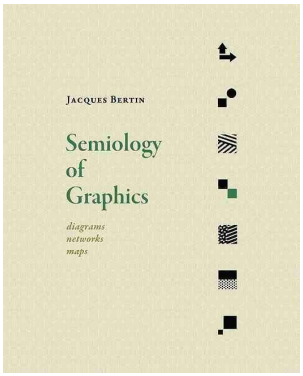
Previous work by Jacques Bertin



Defining Marks and Channels

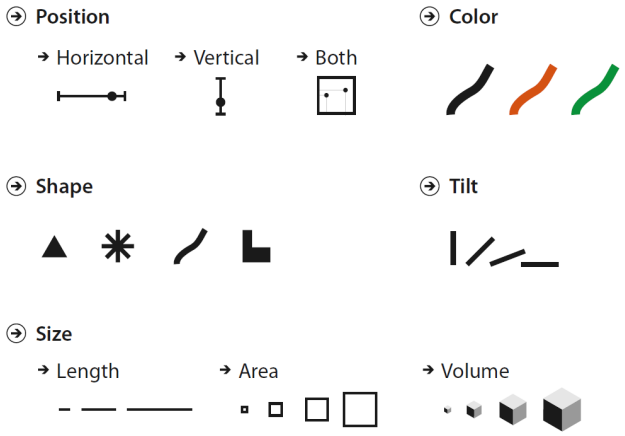
Previous work by Jacques Bertin





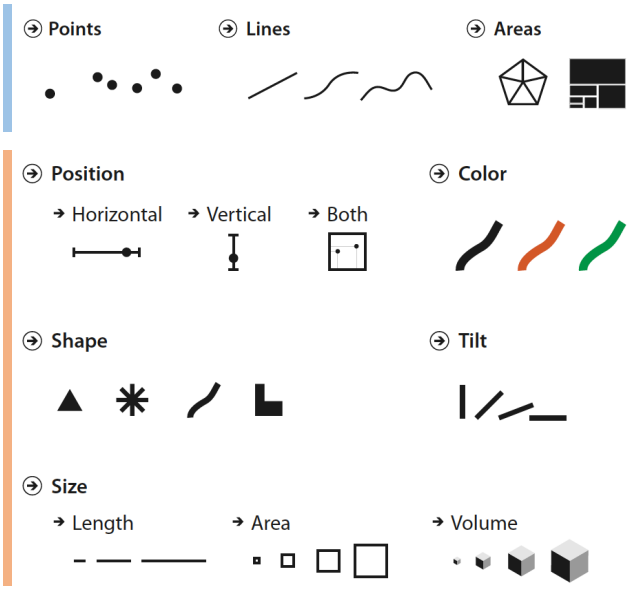
Channels

- A way to control the appearance of marks
- Independent of the spatial dimensionality



Marks and Channels

- Marks
  - geometric primitives
- Channels
  - control appearance of marks
  - can redundantly code with multiple channels
- Interactions
  - point marks only convey position; **no area constraints**
    - **can be size and shape coded**
  - line marks convey position and length
    - **can only be size coded in 1D** (width)
  - area marks *fully constrained*
    - **cannot be size or shape coded**



Analyze Idiom Structure

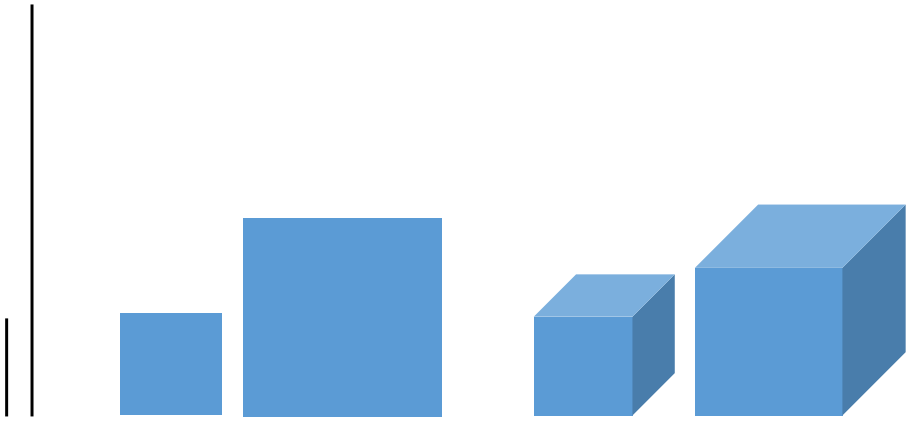
Analyze Idiom Structure

- as combination of marks and channels

1:	2:	3:	4:
vertical position	vertical position horizontal position	vertical position horizontal position color hue	vertical position horizontal position color hue size (area)
mark: line	mark: point	mark: point	mark: point

1D, 2D, and 3D

- size ratio for each pair ➔ 1:4



INTERACTIVE DATA VISUALIZATION: FOUNDATIONS, TECHNIQUES, AND APPLICATIONS, Matthew O. Ward; Georges Grinstein; Daniel Keim, A K Peters Ltd (July 1, 2010)

Expressiveness and Effectiveness

- Expressiveness
  - Vis idiom should express all of, and only, the information in the dataset attributes
- Effectiveness
  - Most important attributes should be encoded with the most effective channels ➔ ranking of channels

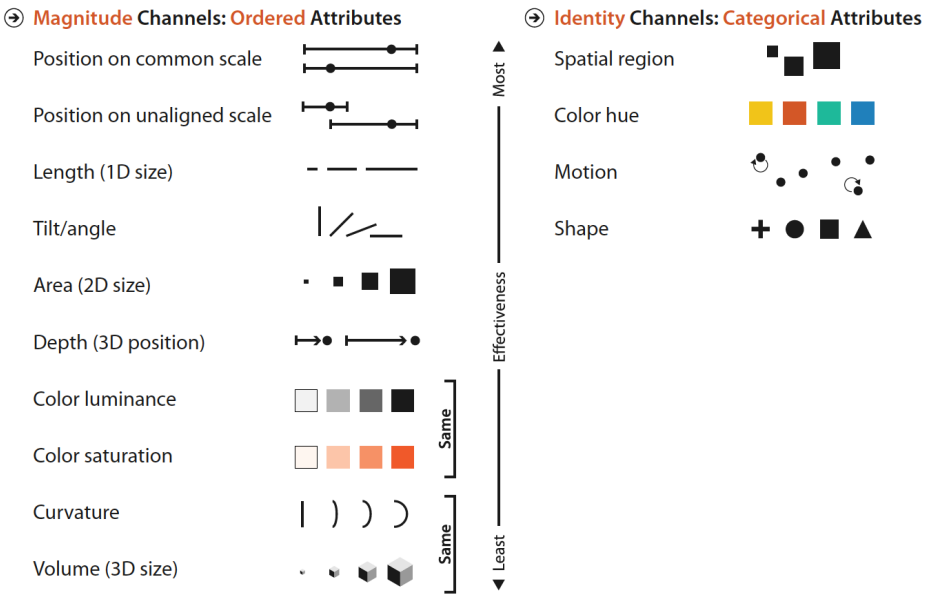
Expressiveness and Effectiveness

- expressiveness principle
  - match channel and data characteristics
- effectiveness principle
  - encode most important attributes with highest ranked channels

- rankings: where do they come from?
  - accuracy
  - discriminability
  - separability
  - popout

[*Automating the Design of Graphical Presentations of Relational Information*. Mackinlay. ACM Trans. on Graphics (TOG) 5:2 (1986), 110–141.]

Channels: Expressiveness types and effectiveness rankings



Stevens' Power Law

- p: perceived magnitude
- a: actual magnitude

- $p = ka^{\alpha}$

- $p_1/p_2 = (a_1/a_2)^{\alpha}$

- length judgment: $\alpha \approx 1$
- area judgment: $\alpha < 1$
- volume judgment: $\alpha \ll 1$

Continuum	Exponent (a)	Stimulus condition
Loudness	0.67	Sound pressure of 3000 Hz tone
Vibration	0.95	Amplitude of 60 Hz on finger
Vibration	0.6	Amplitude of 250 Hz on finger
Brightness	0.33	5° target in dark
Brightness	0.5	Point source
Brightness	0.5	Brief flash
Brightness	1	Point source briefly flashed
Lightness	1.2	Reflectance of gray papers
Visual length	1	Projected line
Visual area	0.7	Projected square
Redness (saturation)	1.7	Red-gray mixture
Taste	1.3	Sucrose
Taste	1.4	Salt
Taste	0.8	Saccharin
Smell	0.6	Heptane
Cold	1	Metal contact on arm

Continuum	Exponent (a)	Stimulus condition
Warmth	1.6	Metal contact on arm
Warmth	1.3	Irradiation of skin, small area
Warmth	0.7	Irradiation of skin, large area
Discomfort, cold	1.7	Whole body irradiation
Discomfort, warm	0.7	Whole body irradiation
Thermal pain	1	Radiant heat on skin
Tactual roughness	1.5	Rubbing emery cloths
Tactual hardness	0.8	Squeezing rubber
Finger span	1.3	Thickness of blocks
Pressure on palm	1.1	Static force on skin
Muscle force	1.7	Static contractions
Heaviness	1.45	Lifted weights
Viscosity	0.42	Stirring silicone fluids
Electric shock	3.5	Current through fingers
Vocal effort	1.1	Vocal sound pressure
Angular acceleration	1.4	5 s rotation
Duration	1.1	White noise stimuli

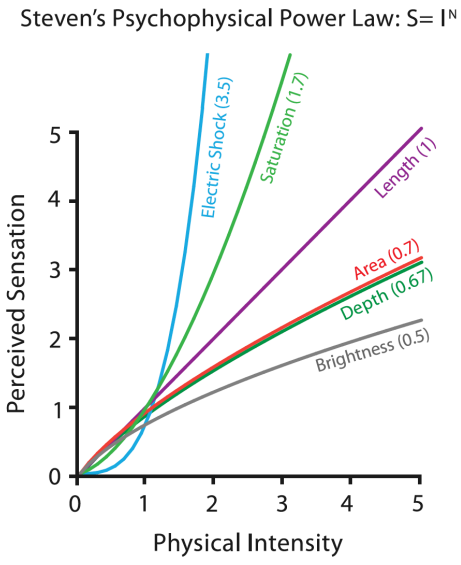
Accuracy: Fundamental Theory

Stevens' Power Law

$$S = I^N$$

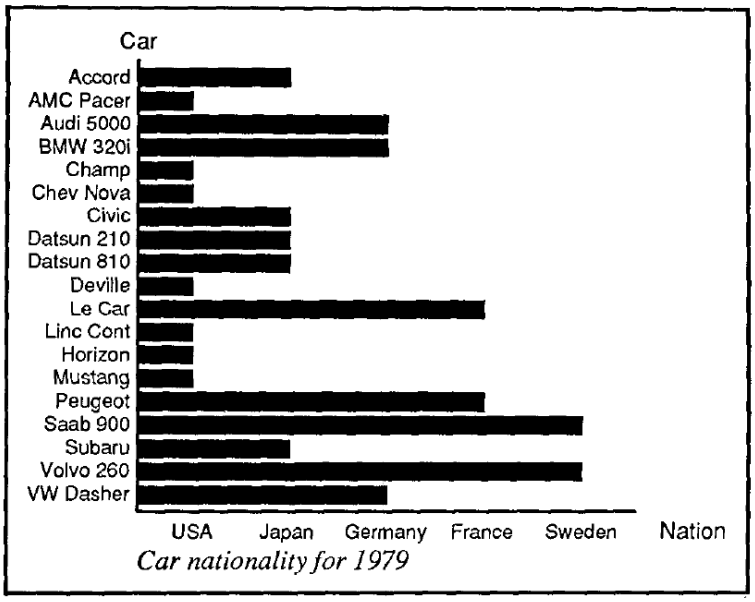
S: perceived magnitude

I: actual magnitude



Information Visualization and Visual Analytics – Marks & Channels

Any Better Encoding?



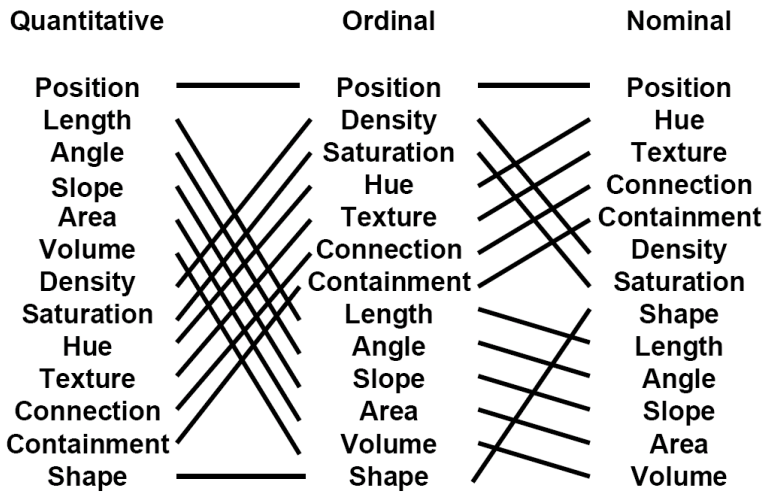
Car nationality for 1979

Channel Rankings

- **Magnitude** Channels for Ordered Attributes
  - Position (aligned scale > unaligned) > Length (1D size) > Tilt/angle > Area (2D size) > Depth > Color (luminance = saturation) > Curvature = Volume (3D size)
- **Identity** Channels for Categorical Attributes
  - Spatial region > Color Hue > Motion > Shape
- **Position** dominates the user's mental model

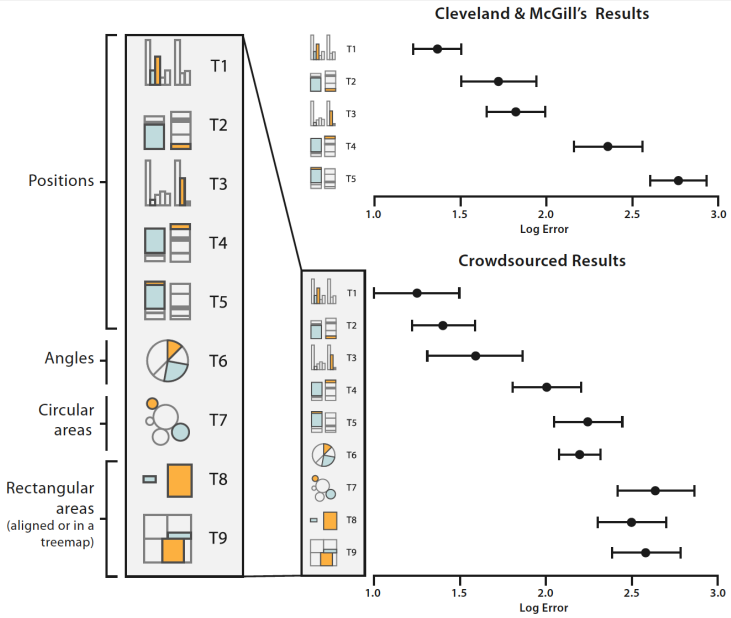
Visual Encoding Principles according to accuracy

- Channel Ranking Varies by Data Type



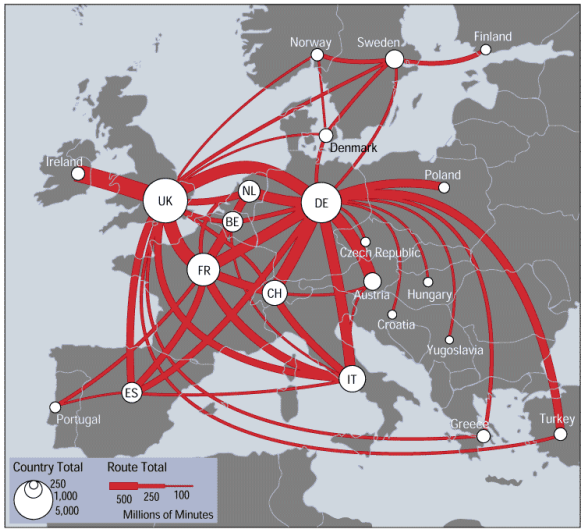
Crowdsourced Results

- T1~T3
  - position along a common scale
- T4~T5
  - length encoding
- T6: angle
- T7: circular area
- T8~T9
  - rectangular area



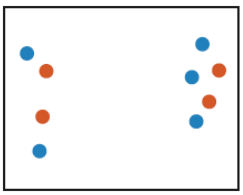
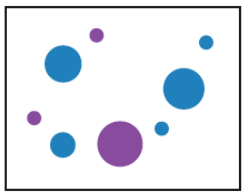
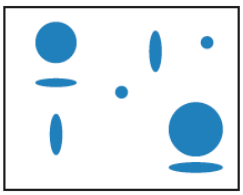
How many usable steps?

- linewidth: only a few

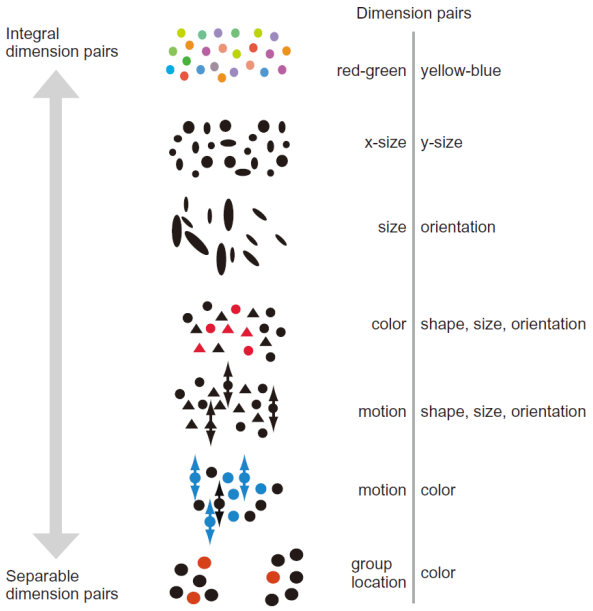


[mappa.mundi.net/maps/maps 014/telegeography.html]

Separable channels vs. Integral channels

Position + Hue (Color)	Size + Hue (Color)	Width + Height	Red + Green
			
Fully separable	Some interference	Some/significant interference	Major interference
2 groups each	2 groups each	3 groups total: integral area	4 groups total: integral hue

Separability

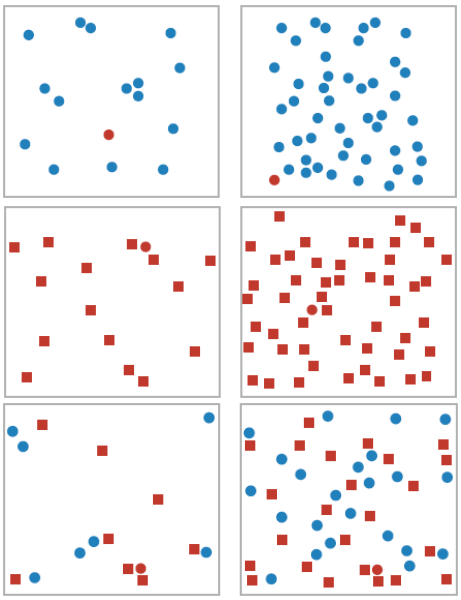


Preattentive Processing

- Cognitive operations done preattentively, without the need for focused attention
  - less than 200-250 ms
    - eye movements take 200 ms
    - minimum time to initiate eye movement
    - involves only information available in a single glance
- Popout effects
- Segmentation effects

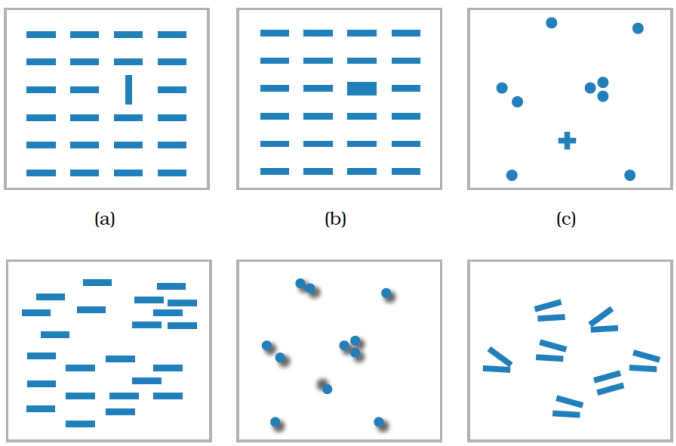
Preattentive Perception

- find the red dot
  - how long does it take?
- parallel processing on many individual channels
  - speed *independent* of # of distractors
  - speed *depends* on channel and amount of difference from distractors
- serial search for (almost all) combinations
  - speed depends on number of distractors

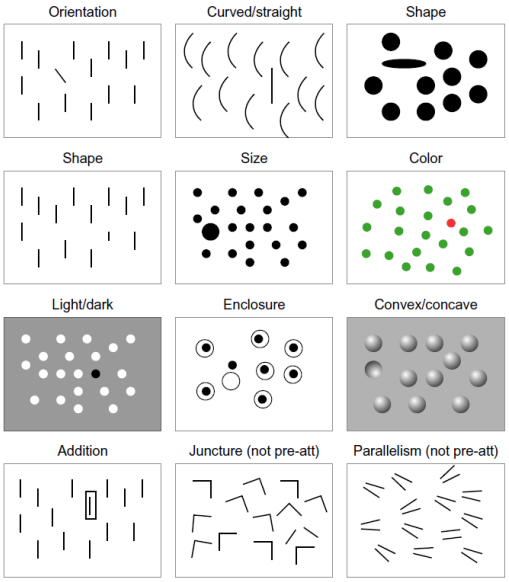


Popout

- many channels: tilt, size, shape, proximity, shadow direction, ...
- but not all! parallel line pairs do not pop out from tilted pairs



Popout

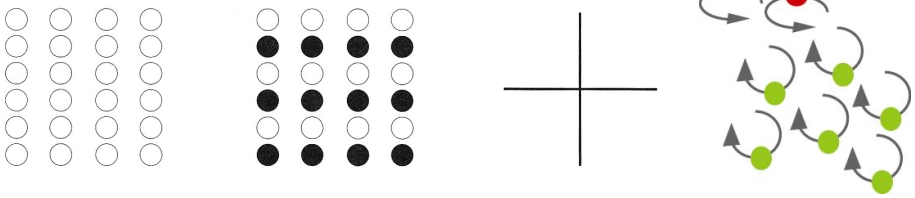


Gestalt Psychology

- Principles of perceptual organization
  - the **whole** is different from the **sum of its parts**
  - how smaller objects are grouped to form larger ones
  - "gestalt": German for "pattern/form/shape"
  - “leaving us with a set of *descriptive* principles, but without a model of perceptual processing”
  - rules themselves still very useful
- Law of Prägnanz
  - law of simplicity, law of good figure
  - fundamental principle of gestalt perception
  - tend to order our experience in a manner that is regular, orderly, symmetric, and simple
  - simplest possibility wins

How do we perceive groups

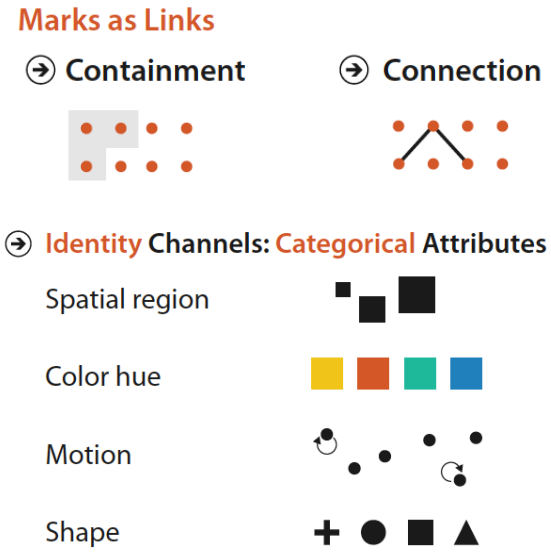
- **Proximity**: tendency of elements to be associated with nearby elements
- **Similarity**: tendency of elements to be associated with similar elements
- **Continuity**: preference for continuous, unbroken, smoothest contours with the *simplest possible physical explanation*
- **Common Fate**: things moving together



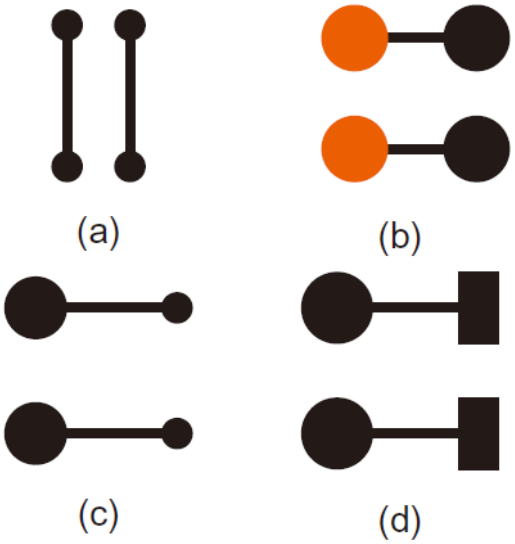
Gestalt Psychology

- containment
- connection

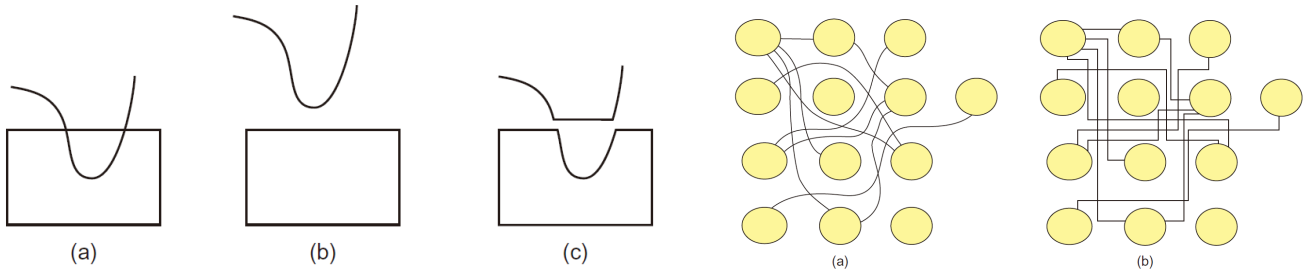
- proximity
  - same spatial region
- similarity
  - same values as other categorical channels



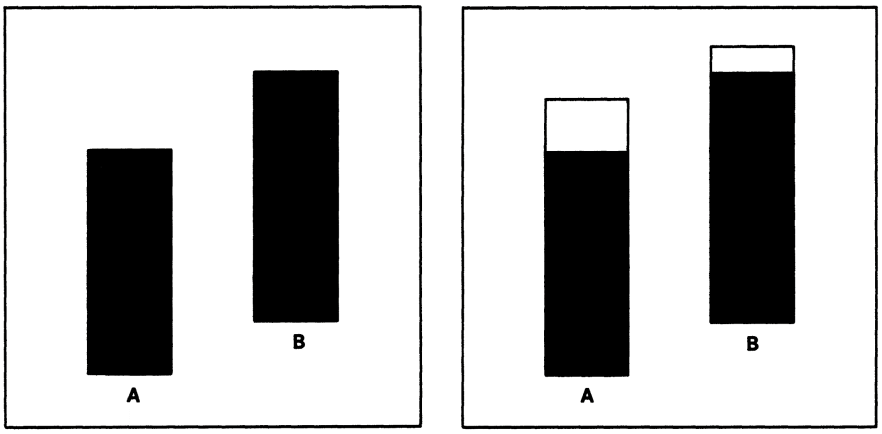
Gestalt laws - Connectedness



Gestalt laws - Continuity



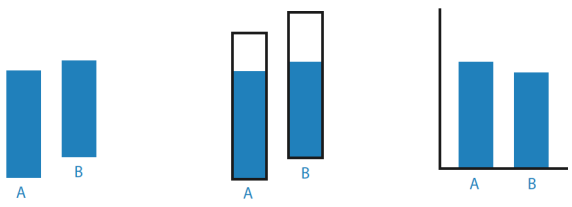
Which is Longer?



Graphical Perception: Theory, Experimentation and the Application to the Development of Graphical Models. William S. Cleveland, Robert McGill, J. Am. Stat. Assoc. 79:387, pp. 531-554, 1984.

Weber's Law

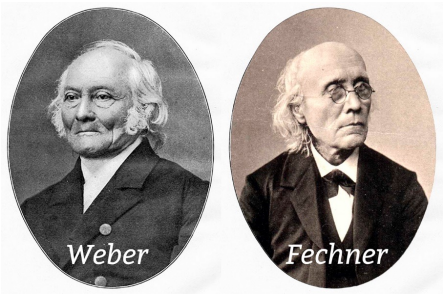
- Perceptual system mostly operates with **relative** judgements, **not absolute**
  - that's why accuracy increases with common frame/scale and alignment
- Weber's Law: the **perceived change** in stimuli is proportional to the **initial stimuli**
  - ratio of increment to background is constant $\frac{(JND)dS}{S} = constant$
  - filled rectangles are long and differ in length by 15% → difficult judgement
  - white rectangles are show and differ in length by 50% → easy judgement



after [Graphical Perception: Theory, Experimentation, and Application to the Development of Graphical Methods. Cleveland and McGill. Journ. American Statistical Association 79:387 (1984), 531–554.]

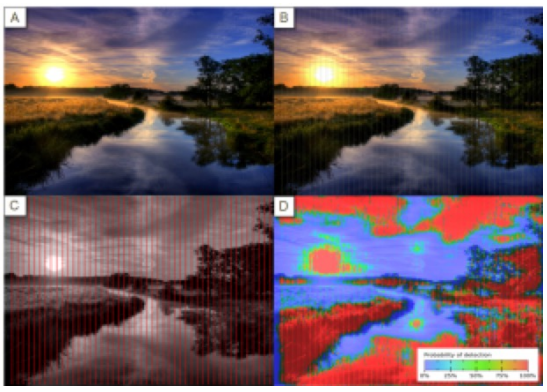
Weber-Fechner's Law

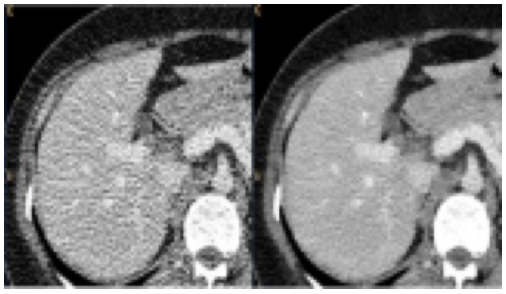
- $\frac{\delta I}{I} = K$, where I is a stimulus intensity and K is a fixed percentage
- **perceived change** in stimuli is proportional to **initial stimuli**
- **detectable difference** in stimulus intensity I as a fixed percentage K of the object magnitude
- JND: just noticeable difference



JND and Visual Perception

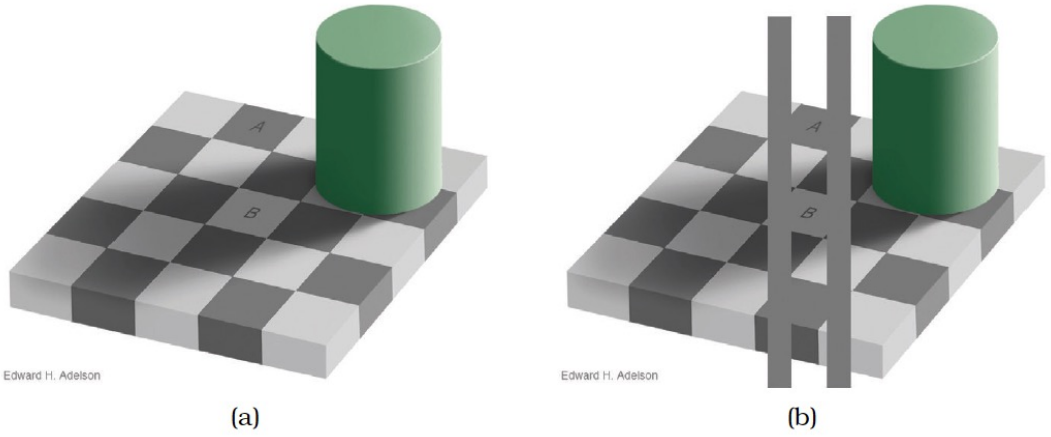
- Contrast sensitivity function
  - Sensitivity of Visual Perception dependes on frequency





Luminance contrast – Simultaneous Brightness Contrast

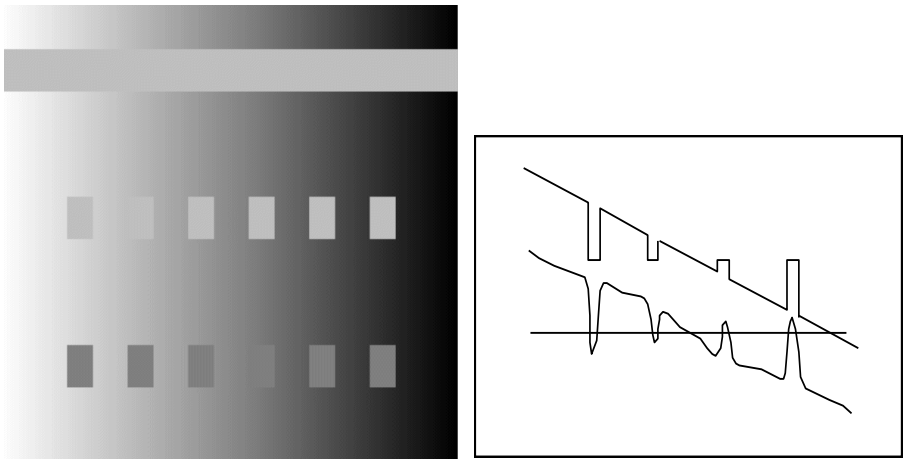
- Perception of color and luminance is contextual
- Luminance perception is based on relative judgements



(a) (b)

Luminance contrast – Simultaneous Brightness Contrast

- Luminance perception is based on relative judgements



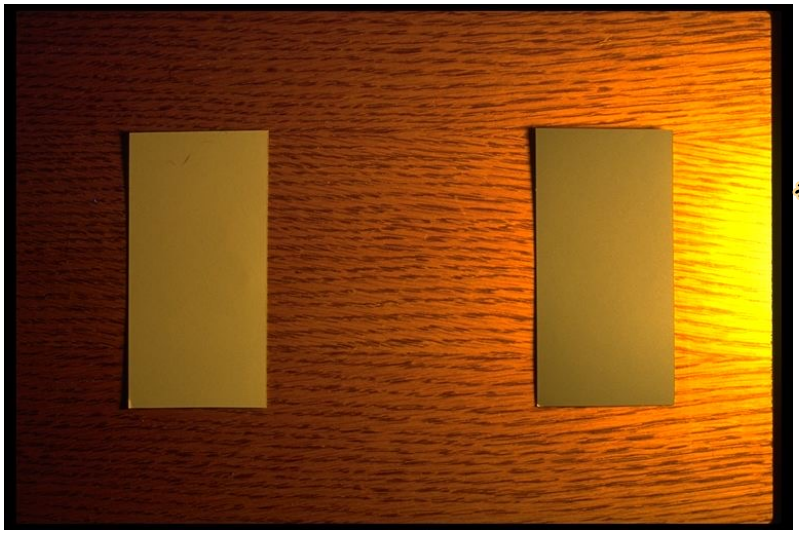
Contrast for constancy

- Does Mild gray paper reflect about the same amount of light as the white paper?

Contrast for constancy

Contrast for constancy

- Does Mild gray paper reflect about the same amount of light as the white paper?



Information Visualization and Visual Analytics – Marks & Channels

Illumination Discounted

- In bright sunlight or moonlight, we can tell whether a surface is black, white, or gray
- Luminance is **completely** unrelated to perceived lightness (or brightness)
  - black paper in full sunlight – 1000 candelas
  - white paper in an office – 50 candelas
- Visual system extracts surface information
- Discounts illumination level
- Discounts color of illumination
- Mechanisms

  Adaptation (photopigments in the receptors – bleach/regenerate)

  Simultaneous brightness contrast (background considered)

Note

- Questions?

References

- Crowdsourcing Graphical Perception: Using Mechanical Turk to Assess Visualization Design. Heer and Bostock. Proc ACM Conf. Human Factors in Computing Systems (CHI) 2010, p. 203–212.
- Automating the Design of Graphical Presentations of Relational Information. Mackinlay. ACM Trans. on Graphics (TOG) 5:2 (1986), 110–141.
- Graphical Perception: Theory, Experimentation and the Application to the Development of Graphical Models. William S. Cleveland, Robert McGill, J. Am. Stat. Assoc. 79:387, pp. 531-554, 1984.
- Many slides from Tamara Munzner's slide deck
- Many figures from Main Textbook by Tamara Munzner