Lecture 1.B: Introduction to data visualization

LSC 563: Data Visualization – Spring 2022

1

Lesson overview

- Data Analytics and data visualization
- Human visual processing
- Perceptual processing
- Low-level visual processing

2

Roles in Data Analytics

3

Roles in Data Analytics: Basic

Data Extraction

Obtain data in an open format
(usually unstructured and messy)

Data Wrangling

Cleaning up and converting
messy data so that it can be
extracted and analyzed

Hannah Winkler Hamalainen, (2014)

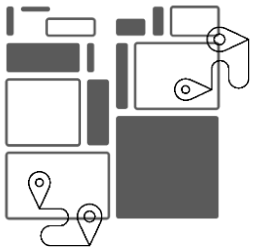
4

Roles in Data Analytics: Advanced

Data Analysis

Exploratory data analysis and summation

Data Visualization



Develop a story and create the visualization

Hannah Winkler Hamalainen, (2014)

5

Introduction to data visualization

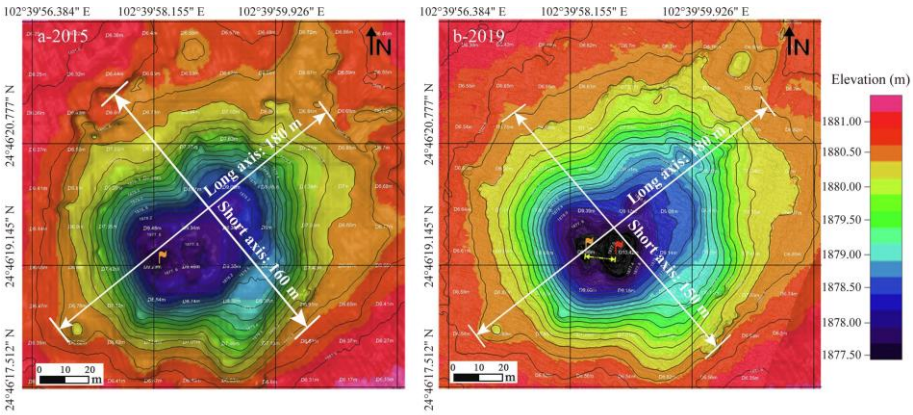
6

What do you notice about this picture?

Wu et al., 2021

7

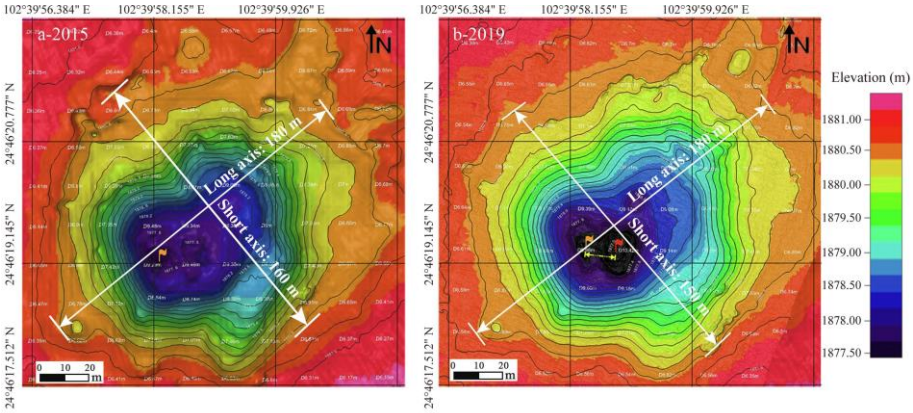
Now what do you see?



Wu et al., 2021

8

Data visualization can reveal so much more



Enlargements of the DEMs of the larger funnel in 2015 and 2019

Wu et al., 2021

9

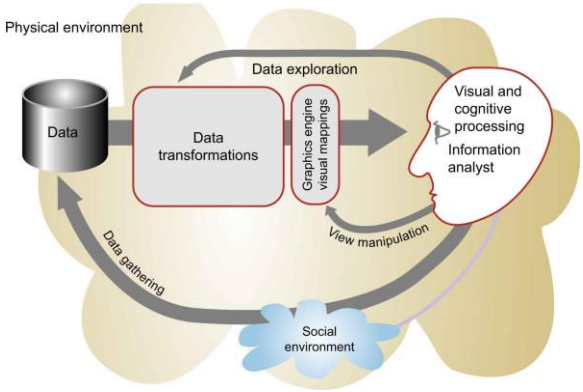
Data visualization can reveal so much more

- Lake Dian image highlights a number of the advantages of visualization:
  - Ability to comprehend huge amounts of data
  - Perception of emergent properties that were not anticipated, which can often be the basis of a new insight.
  - Problems with the data to become immediately apparent, errors and artifacts in the data often jump out at you
  - Understanding of both large-scale and small-scale features of the data, allowing the perception of patterns linking local features.

Ware, 2019a

10

Visualization Stages



Ware, 2019a

- Collection and storage of data, longest feedback loop, involves gathering data
- Preprocessing stage designed to transform the data into something that is easier to manipulate. Often includes data reduction, and data exploration
- Mapping selected data to a visual representation
- Human perceptual and cognitive system (the perceiver)

11

Human visual processing

12

Why might these statements about vision be true?

- Evolutionary conserved?
- Extract useful information from the environment?
- Adapting, based on environment?

Ware, 2019a

13

Why might these statements about vision be true?

- Visual system has survival value
- Navigation
- Food seeking (which is an optimization problem like information seeking)
- Using tools (which depends on object-shape perception)

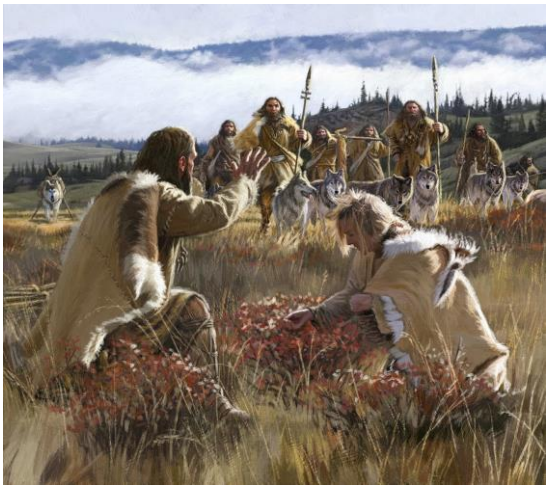


Image source

Ware, 2019a

14

Visible light

- Perception is about understanding patterns of light
- Visible light constitutes a very small part of the electromagnetic spectrum

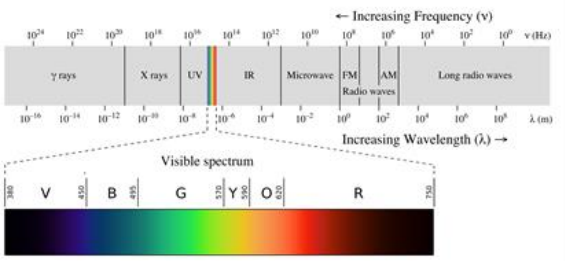


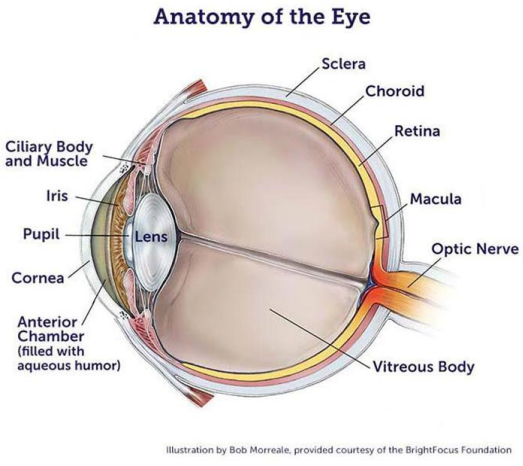
Image source

Ware, 2019a

15

Mechanism of sight

- About 70% of the sense receptors are dedicated to vision
- Major components of the eye:
  - Cornea protects the eye
  - Iris controls the size of the pupil
  - Pupil controls how much light enters to the eye
  - Lens focuses on objects
  - Retina is the rear surface of the eye, coated with millions of specialized nerve cells
  - Optic nerve transmits visual information from the retina to the brain.



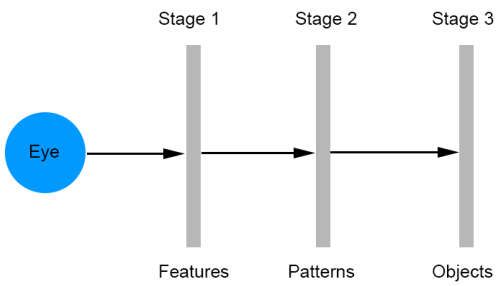
Ware, 2019a

16

Perceptual Processing

17

A Model of Perceptual Processing



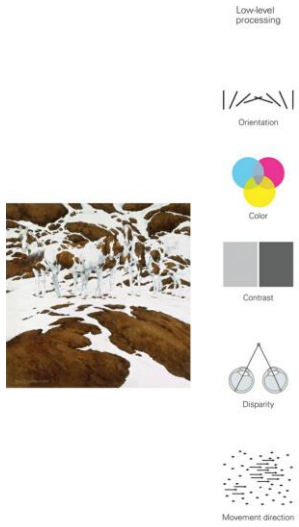
- The brain analyzes a visual scene at three stages:
  - Stage 1 (low-level processing)
  - Stage 2 (intermediate-level processing)
  - Stage 3 (high-level processing)

Ware, C. (2013).

18

Mechanism of sight: Stage 1

- Orientation, color, texture, and movement
- Processing is parallel, unconscious, and transitory
- Stored in iconic memory, which works kind of like a buffer for the sensory information

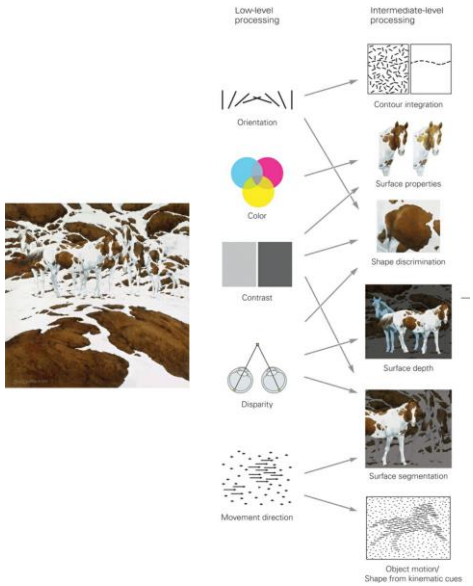


Ware, 2019c

19

Mechanism of sight: Stage 2

- Layout of scenes and of surface properties
- Parsing the visual image into surfaces and global contours
- Foreground from background
- Low level features are aggregated together to create patterns

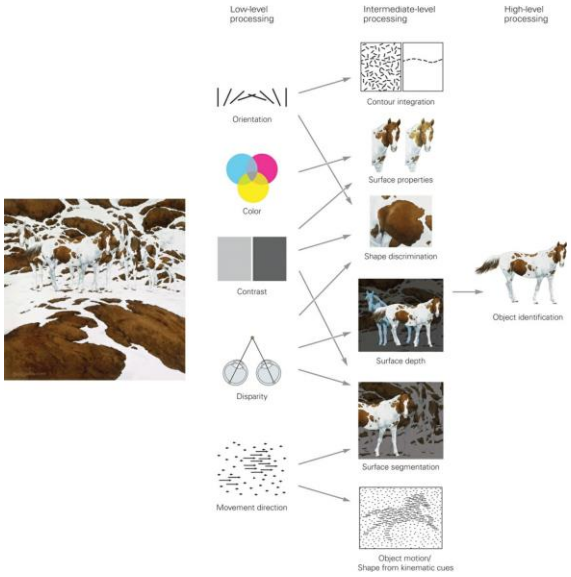


Ware, 2019c

20

Mechanism of sight: Stage 3

- Detected patterns through previous stages are transformed into objects that are retained in working memory
- The objects can be matched with memories of shapes and their associated meanings



Ware, 2019c

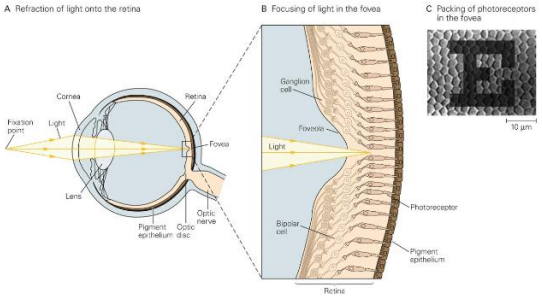
21

Stage 1: Low-level Processing

22

“Basic” Process of Vision

- Vision occurs in the following stages:
  - Light from an object in the visual field is refracted by the cornea and lens and focused onto the retina
  - Image is projected onto the densely packed photoreceptors in the fovea
  - The photoreceptor cells absorb light and convert it into a neural signal, an essential process known as phototransduction



Kandel, E. R. (2013).

23

Low-level Visual Processing: Attributes

- The retinal circuit performs low-level visual processing as it extracts the raw images in the left and right eyes
- Low-level processing is very plastic, with the retina is constantly adjusting its sensitivity to ever-changing conditions of illumination
- This adaptation provides stability despite the vast range of light intensities encountered by the retina

Kandel, E. R. (2013).

24

Rods and Cones

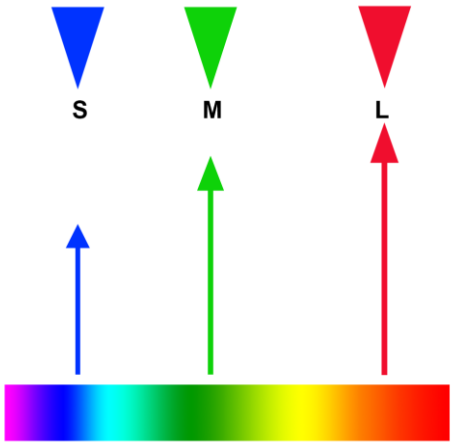
- Most vertebrates have two types of photoreceptors: rods and cones
- Rods and cones differ in photosensitivity:
  - Rods specialize in sensing dim light and record what they detect in black and white
  - Cones specialize in sensing brighter light and record what they detect in color

Meister & Tessier-Lavigne, 2013

25

Trichromacy

- Primates have three kinds of cone photoreceptors, distinguished by the range of wavelengths to which they respond:
  - Short wavelength (S), the "blue" cones
  - Medium wavelength (M), the "green" cones
  - Long wavelength (L), the "red" cones

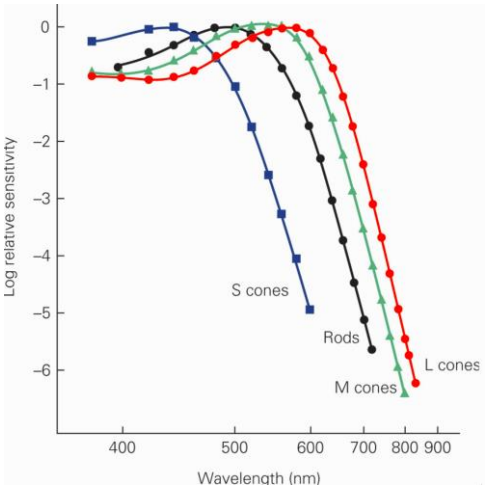


Meister & Tessier-Lavigne, 2013

26

Trichromacy and Color Perception

- Light of different wavelengths is absorbed by the three different receptor types (S, M, L)
- What does this really mean?
  - Different photoreceptors are sensitive to broad and overlapping ranges of wavelengths
  - For example, at 600 nm the blue cones were nearly 105 times less sensitive than the red and green cones



Meister & Tessier-Lavigne, 2013

Image source: Schnapf et al., 1988

27

Color Perception Curve

- Yellow and green hues at the curve's height and red and violet forming its lower extremities
- Certain colors are perceived more easily than others:
  - Yellows and greens are seen before other hues
  - Red and violet are the most difficult to perceive

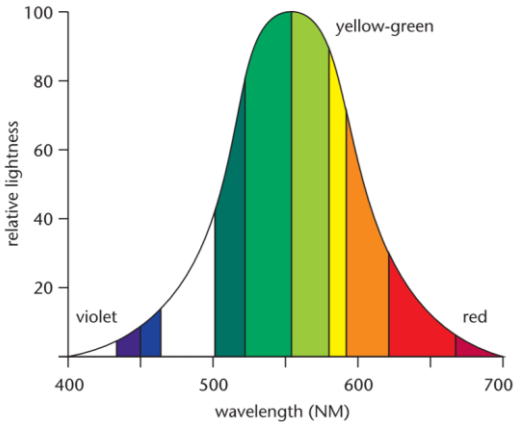
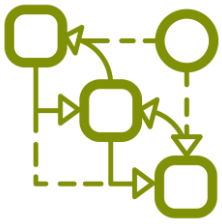


Image source: Feisner & Reed, 2014

Feisner & Reed, 2014

28



Theories of Color Vision

29

History of Color Theory

- We have always been fascinated by the perception of color
- Fueled by the relevance of color to art, and commercial interests in television and photography
- Colorimetry (measurement of color) is a measure of visual function at the photoreceptor level and is based on techniques of color matching
- Colorimetry goes back to the days of Newton, Helmholtz and Maxwell

Meister & Tessier-Lavigne, 2013

30

Major Color Theories

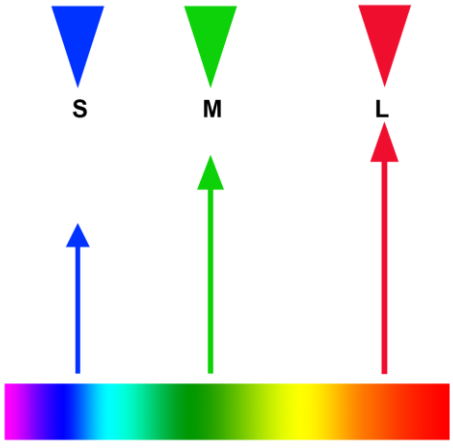
- Two major theories explain processes that operate at different levels of the visual system
  - Trichromatic theory
  - Opponent-process theory
  - Both based on psychophysics that placed strong constraints on the underlying neural mechanisms

Meister & Tessier-Lavigne, 2013

31

Trichromacy Theory

- This theory explains color vision phenomena at the photoreceptor level
- Developed based on the work of Maxwell, Young, and Helmholtz
- Three types of receptors, approximately sensitive to the red, green, and blue regions of the spectrum

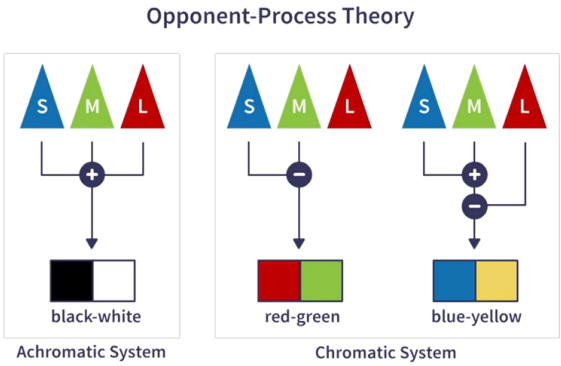


Fairchild, 2013

32

Opponent-Process Theory

- States that the signal that is received creates three different types of channels:
  - Red-green axis
  - Blue-yellow axis
  - Black-white (luminance) axis or the amount of light that is given by a particular color
- Most important in terms of color vision deficiency



33

Bibliography

- Fairchild, M. D. (2013). Human color vision [Book Section]. In M. D. Fairchild (Ed.), Color appearance models (pp. 1–37). https://doi.org/10.1002/9781118653128.ch1
- Feisner, E. A., & Reed, R. (2014). What is color? [Book Section]. In Color studies (Third edition /, pp. xvi, 279 pages). Fairchild Books.
- Forrester, J. V., Dick, A. D., McMenamin, P. G., Roberts, F., & Pearlman, E. (2016a). Chapter 1 - anatomy of the eye and orbit [Book Section]. In J. V. Forrester, A. D. Dick, P. G. McMenamin, F. Roberts, & E. Pearlman (Eds.), The eye (fourth edition) (pp. 1–102.e2). W.B. Saunders. https://doi.org/https://doi.org/10.1016/B978-0-7020-5554-6.00001-0
- Forrester, J. V., Dick, A. D., McMenamin, P. G., Roberts, F., & Pearlman, E. (2016b). Chapter 5 - physiology of vision and the visual system [Book Section]. In J. V. Forrester, A. D. Dick, P. G. McMenamin, F. Roberts, & E. Pearlman (Eds.), The eye (fourth edition) (pp. 269–337.e2). W.B. Saunders. https://doi.org/https://doi.org/10.1016/B978-0-7020-5554-6.00005-8

34

Bibliography

- Kandel, E. R. (2013a). Sensory coding [Book Section]. In E. R. Kandel, J. H. Schwartz, T. M. Jessell, S. A. Siegelbaum, & A. J. Hudspeth (Eds.), Principles of neural science (5th ed.). McGraw-Hill Medical.
- Kandel, E. R. (2013b). The constructive nature of visual processing [Book Section]. In E. R. Kandel, J. H. Schwartz, T. M. Jessell, S. A. Siegelbaum, & A. J. Hudspeth (Eds.), Principles of neural science (5th ed.). McGraw-Hill Medical.
- Meister, M., & Tessier-Lavigne, M. (2013). Low-level visual processing: The retina [Book Section]. In E. R. Kandel, J. H. Schwartz, T. M. Jessell, S. A. Siegelbaum, & A. J. Hudspeth (Eds.), Principles of neural science (5th ed.). McGraw-Hill Medical.
- Schnapf, J. L., Kraft, T. W., & Baylor, D. A. (1987). Spectral sensitivity of human cone photoreceptors [Journal Article]. Nature, 325, 439. https://doi.org/10.1038/325439a0

35

Bibliography

- Ware, C. (2019b). Foundations for an applied science of data visualization [Book Section]. In Information visualization: Perception for design (4th ed., pp. 1–30). Morgan Kaufmann (Elsevier). https://doi.org/10.1016/B978-0-12-812875-6.00001-3
- Ware, C. (2019c). The environment, optics, and the display [Book Section]. In Information visualization: Perception for design (4th ed., pp. 31–68). Morgan Kaufmann (Elsevier). https://doi.org/10.1016/B978-0-12-812875-6.00002-5
- Wichmann, F. A., Sharpe, L. T., & Gegenfurtner, K. R. (2002). The contributions of color to recognition memory for natural scenes [Journal Article]. Journal of Experimental Psychology: Learning, Memory, and Cognition, 28(3), 509–520. https://doi.org/10.1037//0278-7393.28.3.509

36