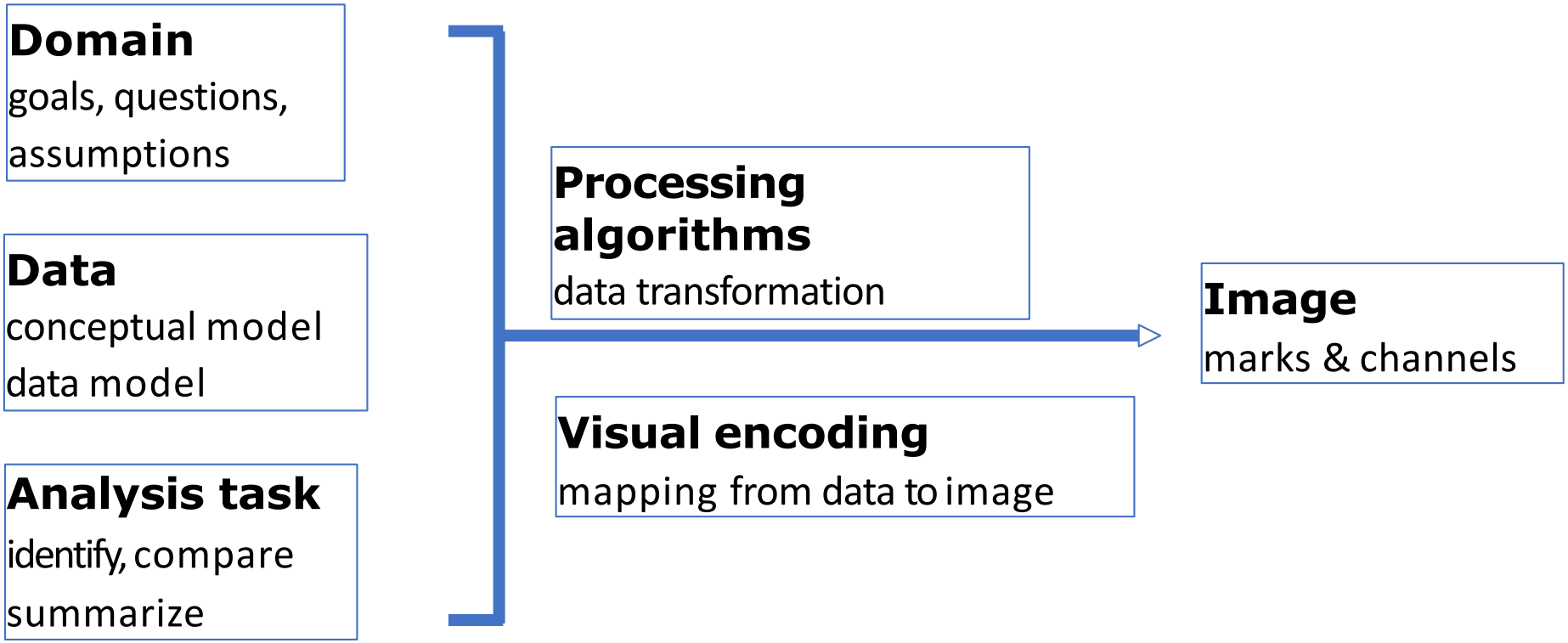
ĐẠI HỌC BÁCH KHOA HÀ NỘI
VIỆN CÔNG NGHỆ THÔNG TIN VÀ TRUYỀN THÔNG

Lecture 7
Visual Model & Visual Encoding

Goal

Learn how data is mapped to images

The Big Picture



[Slides from J. Heer]

Topics

- Properties of Data
- Properties of Images
- Visual encoding: Mapping Data to Images

Properties of Data

Taxonomy of Datasets

1D (sets and sequences)

Temporal

2D (maps) 3D

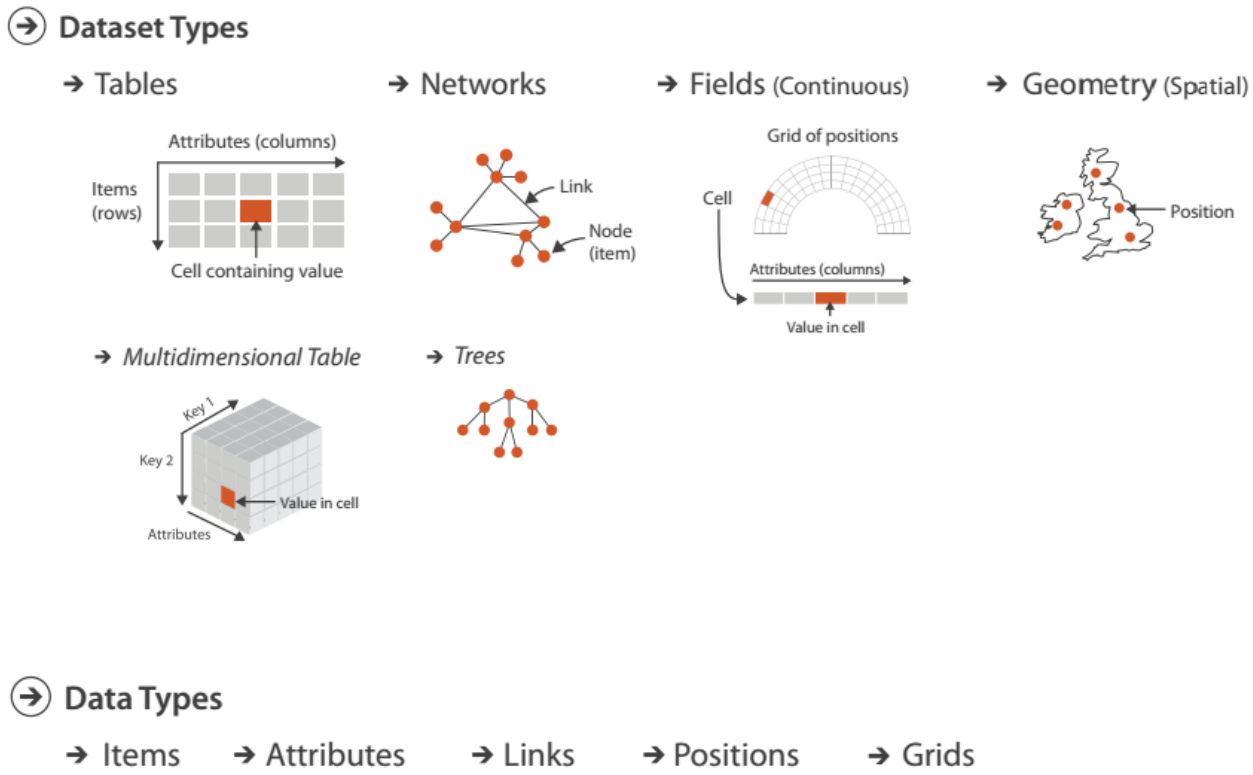
(shapes) nD

(relational)

Trees (hierarchies)

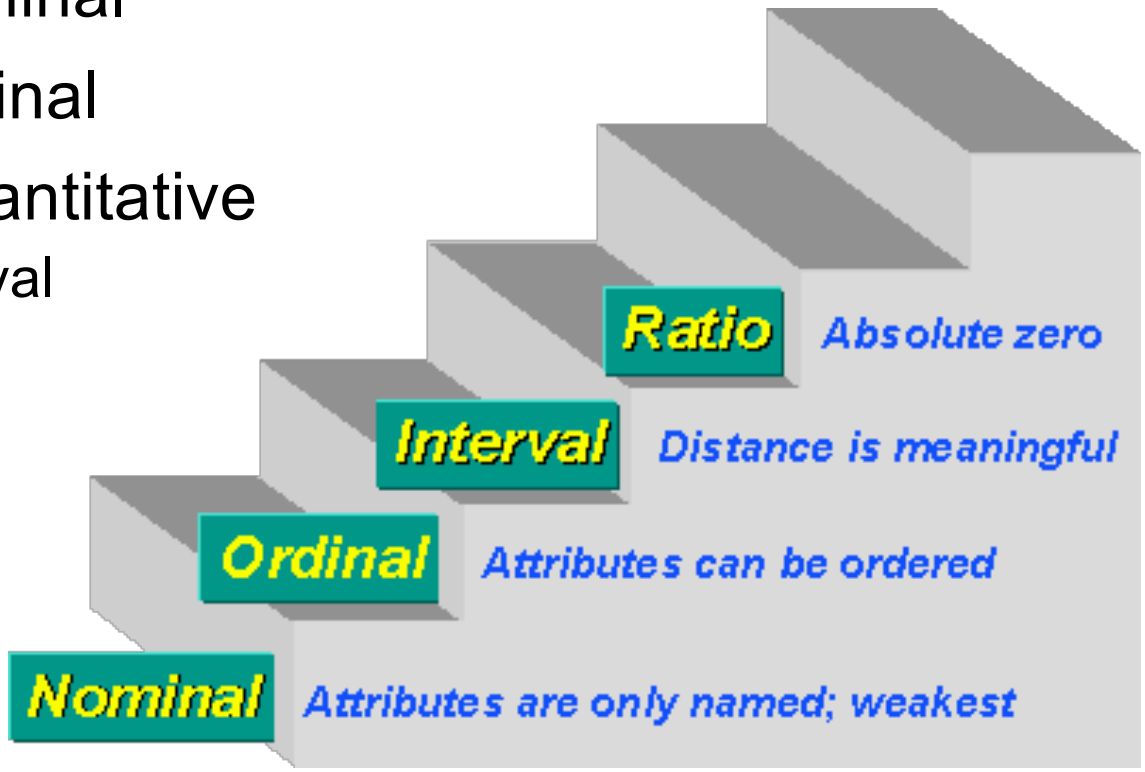
Networks (graphs)

and combinations…



Levels of measurement

- Stevens (1946) classified variables into four levels. These are refererred to as levels of measurement, or levels of data.
- N - Nominal
- O - Ordinal
- Q – Quantitative
  - Interval
  - Ratio



Nominal level measurement

- Merely classifies units into non-ordered categories
- Examples
  - Male/Female
  - Eye colors
  - Car models

Ordinal level measurement

- Classifies units into ranks or ordered categories
- Examples
  - Ranks: 1st, 2nd, 3rd... place finishers in race
  - Ordered categories: {none = 0, low=1, medium=2, high=3}

Interval level measurement

- Distances (absolute differences) are meaningful
  - any arithmetic operation, such as multiplication, is not
- A fixed difference anywhere on the measurement scale always corresponds to the same difference on the trait being measured
- The zero state of an interval scale is not a true zero value
  - A temperature reading of 0°C does not mean there is no temperature
- Examples
  - Temperature °F
  - A one-degree temperature (°F) difference always means the same thing
  - The absolute difference between 60°F and 61°F is the same as between 100°F and 101°F

Ratio level measurement

- Both differences and ratios are meaningful
- There is a true zero
  - A zero on a ratio scale means there is a total absence of the variable you are measuring.
- Examples
  - Length, area, and population
  - The relative difference between a 10- and a 20-year-old is the same as the difference between a 40- and an 80-year-old (‘twice as old’).
  - Celsius and Fahrenheit are interval scales, Kelvin is a ratio scale
    - Kelvin scale has a true zero (0 K) where nothing can be colder.
    - Zero is just another temperature value in Celsius and Fahrenheit

Properties of images

Image Models

Visual Language is a Sign System

Images perceived as a set of signs

Sender encodes information in signs

Receiver decodes information from signs

Semiology of Graphics, 1967

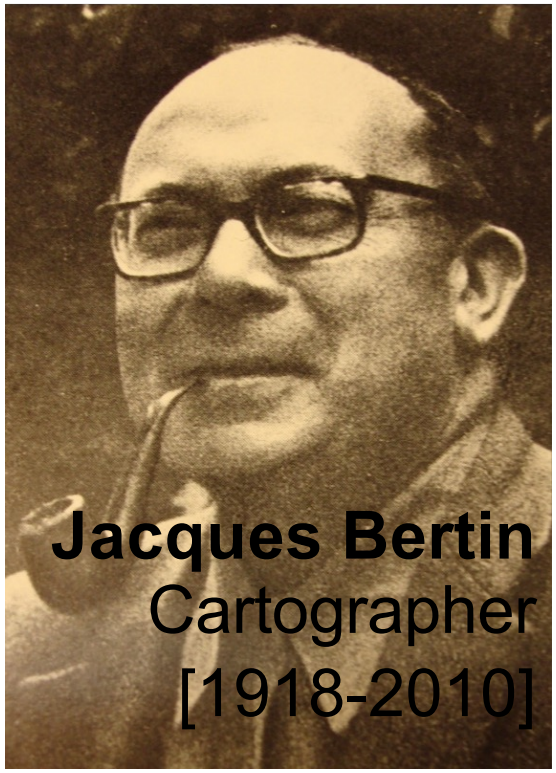


Image Models

Visual Marks (Đối tượng biểu diễn)

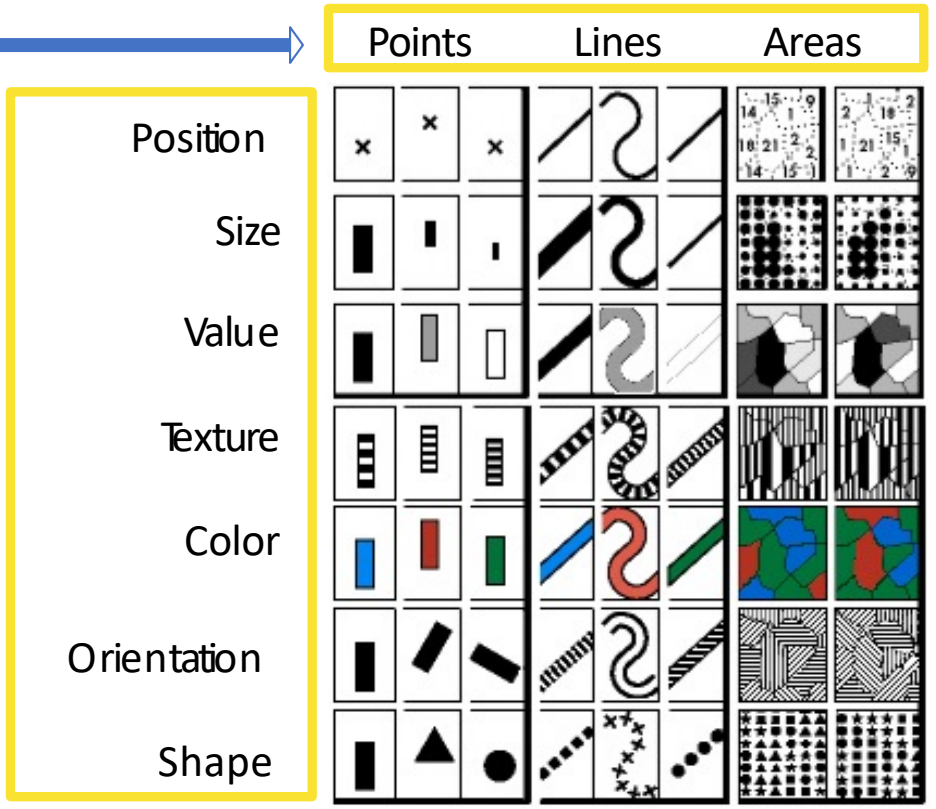
Basic graphical elements in an image

Represent information

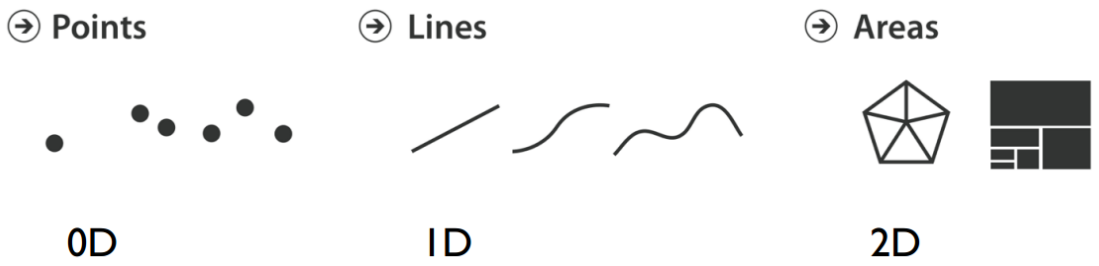
Perceptual Channels (Biến thị giác)

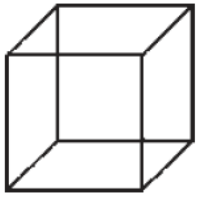
Control the appearance of marks

Encode information



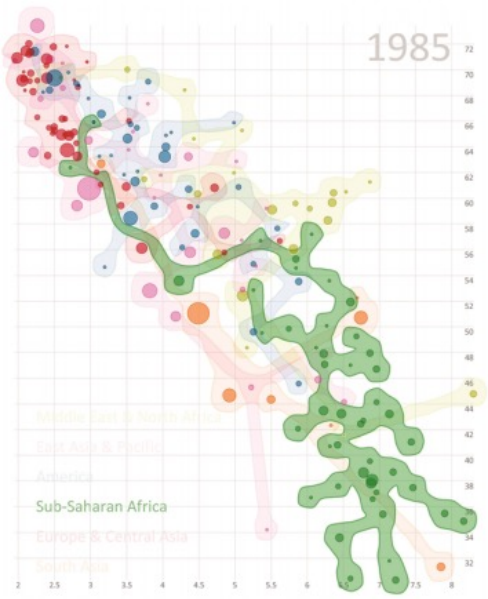
Visual marks to represent items



MARK	EXAMPLE	DESCRIPTION
Point		The *point* mark is commonly used as a marker to represent quantitative values through position on a scale, forming the basis of, for example, the scatter plot.
Line		The *line* mark is commonly used to represent quantitative values through variation in size (length), forming the basis of, for example, the bar chart.
Shape		The *shape* mark is commonly used to represent quantitative values through variation in size and position, forming the basis of, for example, the bubble plot.
Form		The *form* mark is used to represent quantitative values through variation in size (volume), forming the basis of charts that encode 3D representations.

Visual marks to represent links

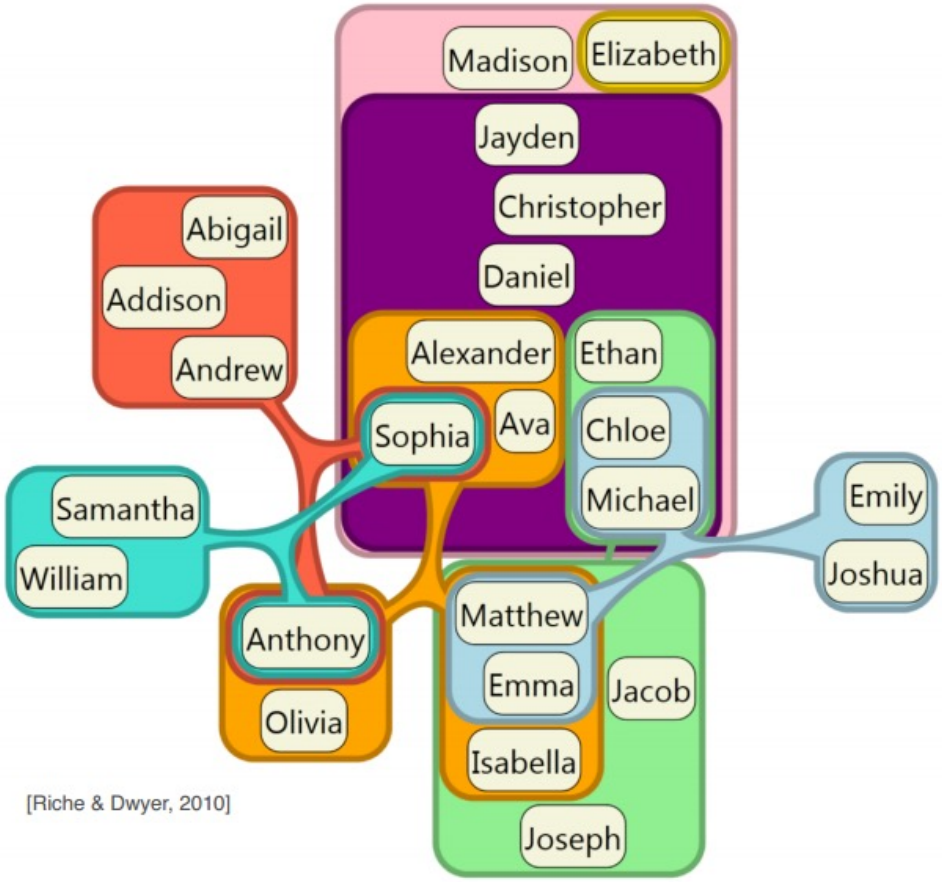
Containment



Connection

Visual marks to represent links (2)

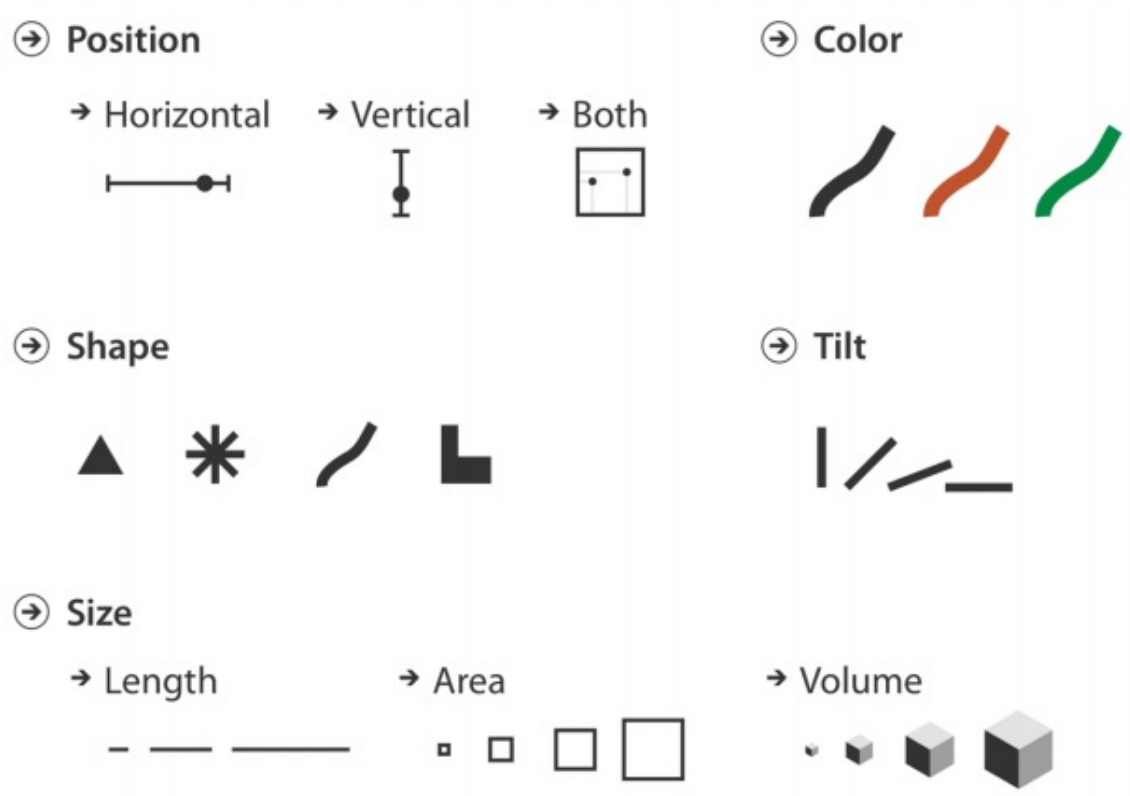
Nested containment



[Riche & Dwyer, 2010]

Perceptual Channels

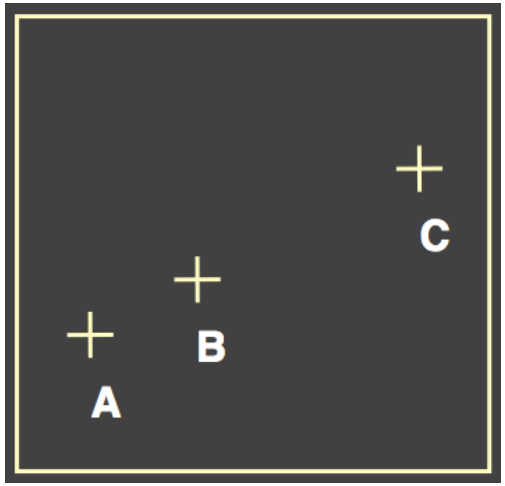
- Control the appearance of marks
- Encode information



Perceptual channels: Position

- Can encode quantitative variables (Q)

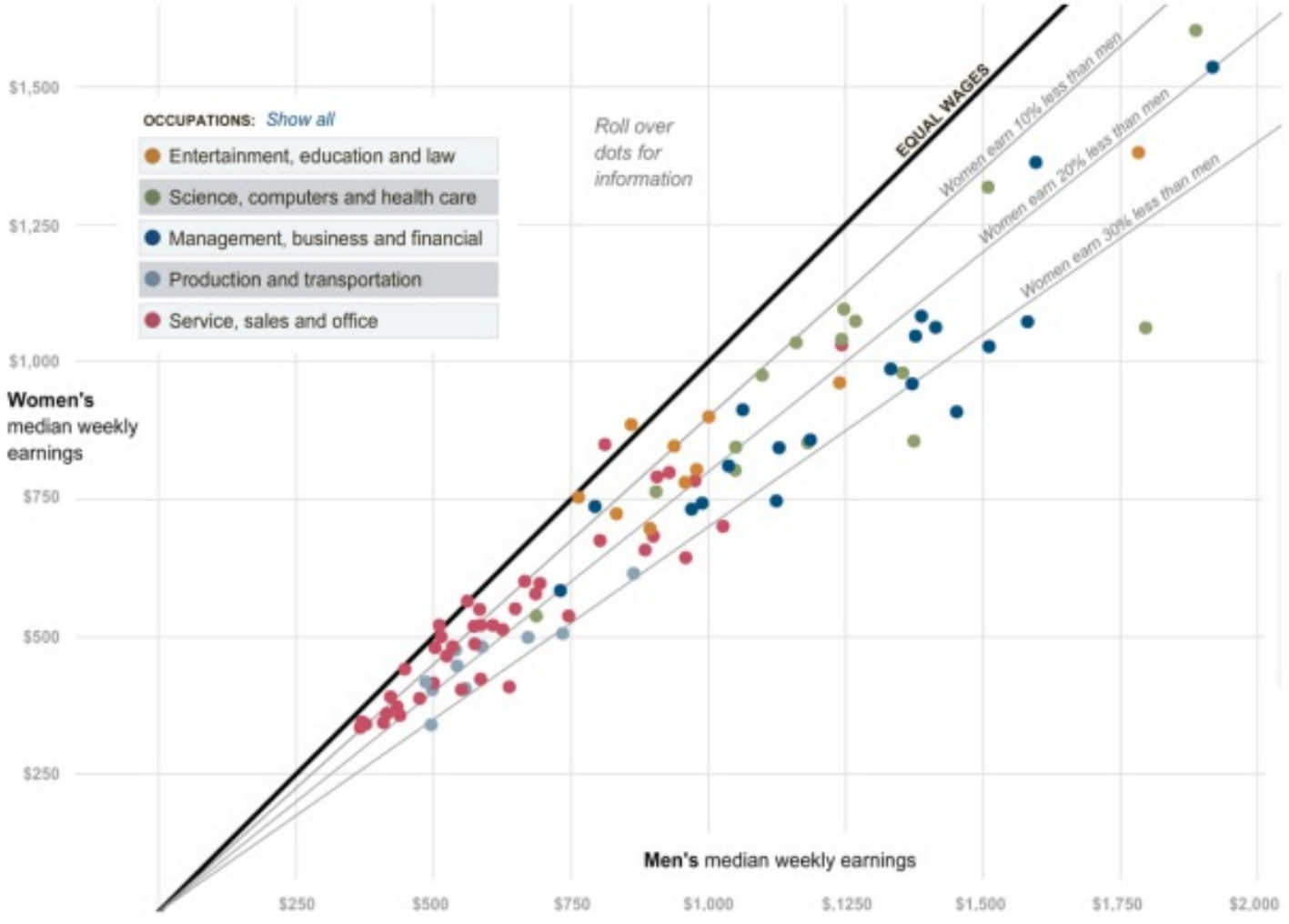
1. A, B, C are distinguishable
2. B is between A and C.
3. BC is twice as long as AB.



"Resemblance, order and proportional are the three signfields in graphics." — Bertin

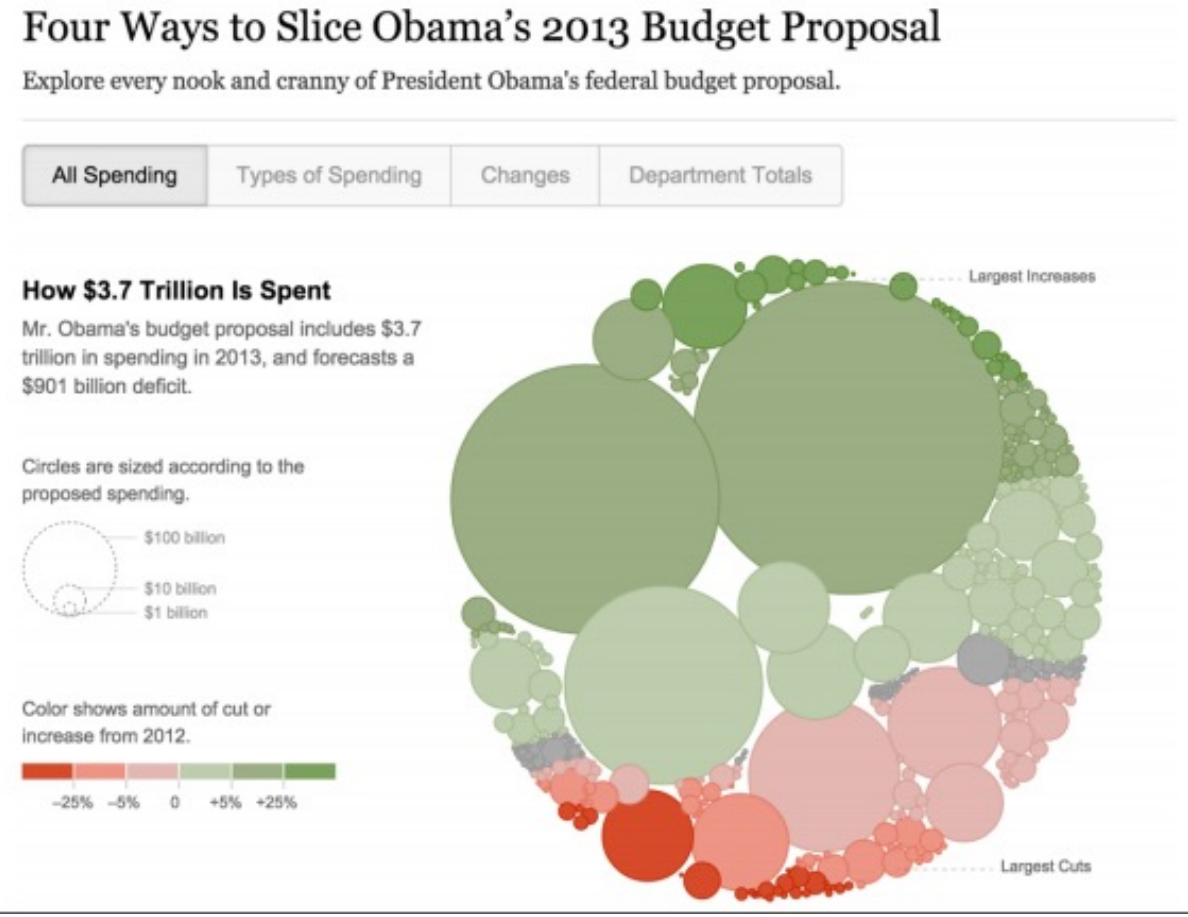
Perceptual channels: Position

- The most used perceptual channel
- Suitable for most data types



Perceptual channels: Size

- Length, area, volume
  - Good for 1D, 2D
  - Easy to compare



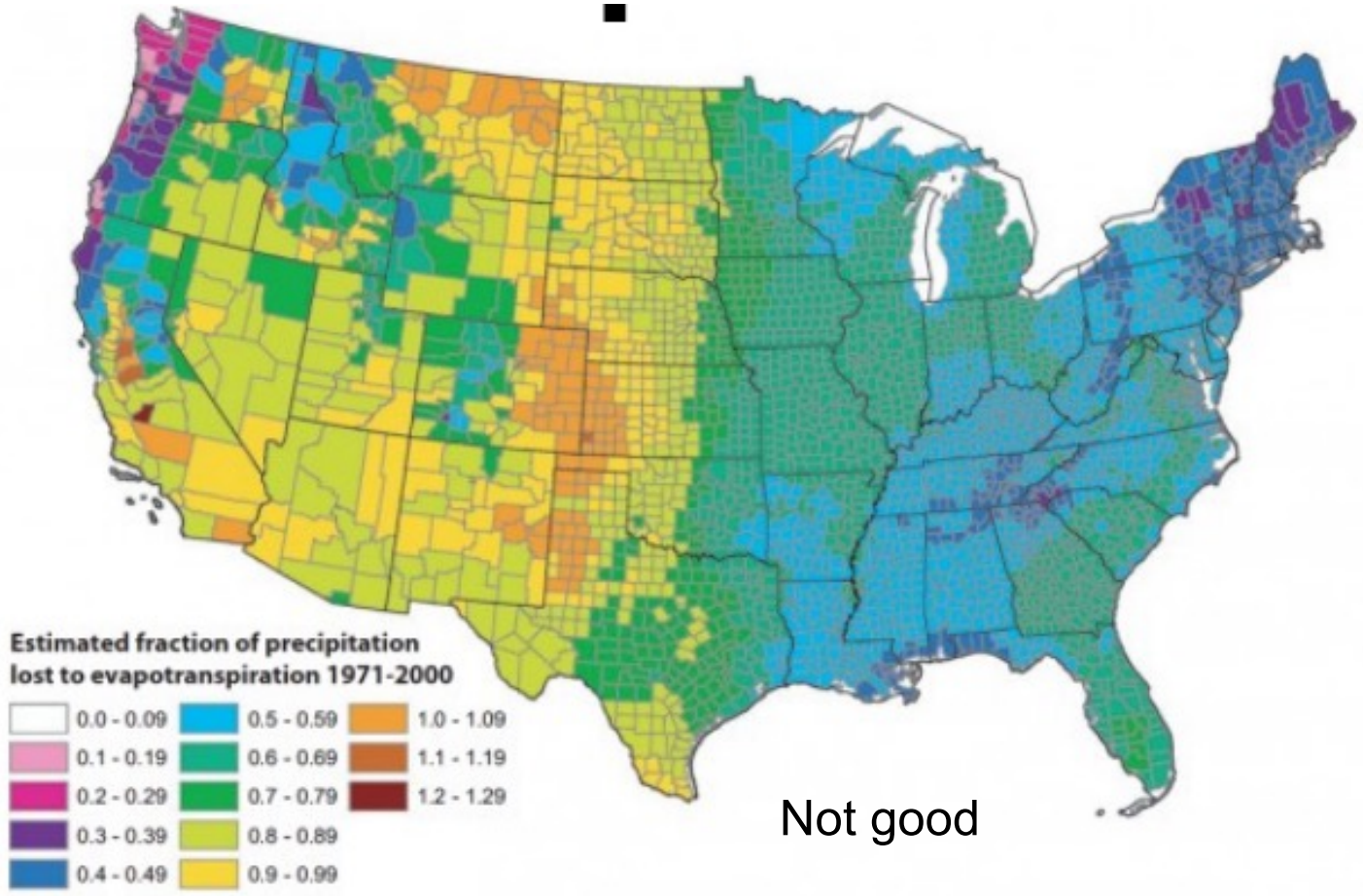
Encoding Information in Color and Value

- Value (lightness) is perceived as ordered
  - Encode ordinal variables (O) *[better]*
  - Encode continuous variables (Q)

- Hue is normally perceived as unordered
  - Encode nominal variables (N)

Perceptual channels: Color

- Should limit the number of colors



Not good

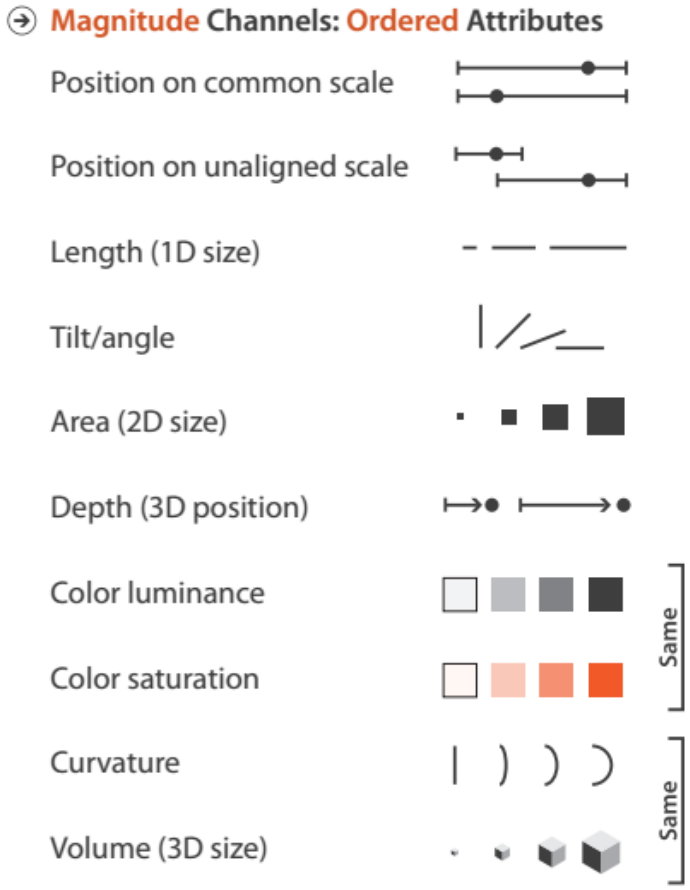
FIGURE 13. Estimated Mean Annual Ratio of Actual Evapotranspiration (ET) to Precipitation (P) for the Conterminous U.S. for the Period 1971-2000. Estimates are based on the regression equation in Table 1 that includes land cover. Calculations of ET/P were made first at the 800-m resolution of the PRISM climate data. The mean values for the counties (shown) were then calculated by averaging the 800-m values within each county. Areas with fractions >1 are agricultural counties that either import surface water or mine deep groundwater.

Perceptual channels: Shape

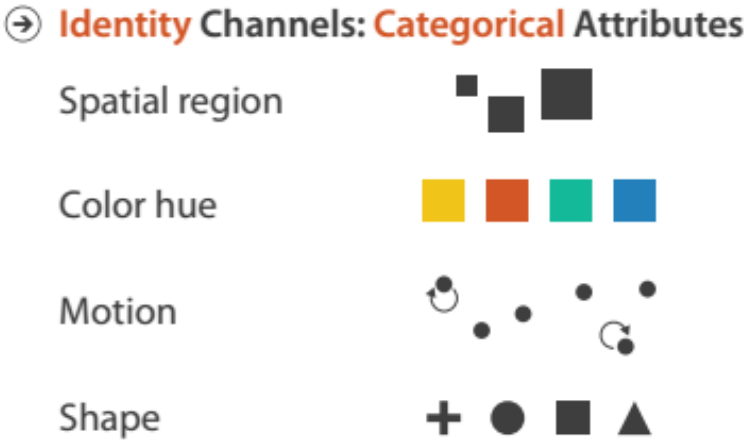
- Encode nominal variables (N)
- No ordered

Encoding information in perceptual channels

Quantitative/Ordered



Nominal



Bertin's Levels of Organization

Position	N	O	Q
Size	N	O	Q
Value	N	O	Q
Texture	N	o	
Color	N		
Orientation	N		
Shape	N		

Nominal

Ordinal

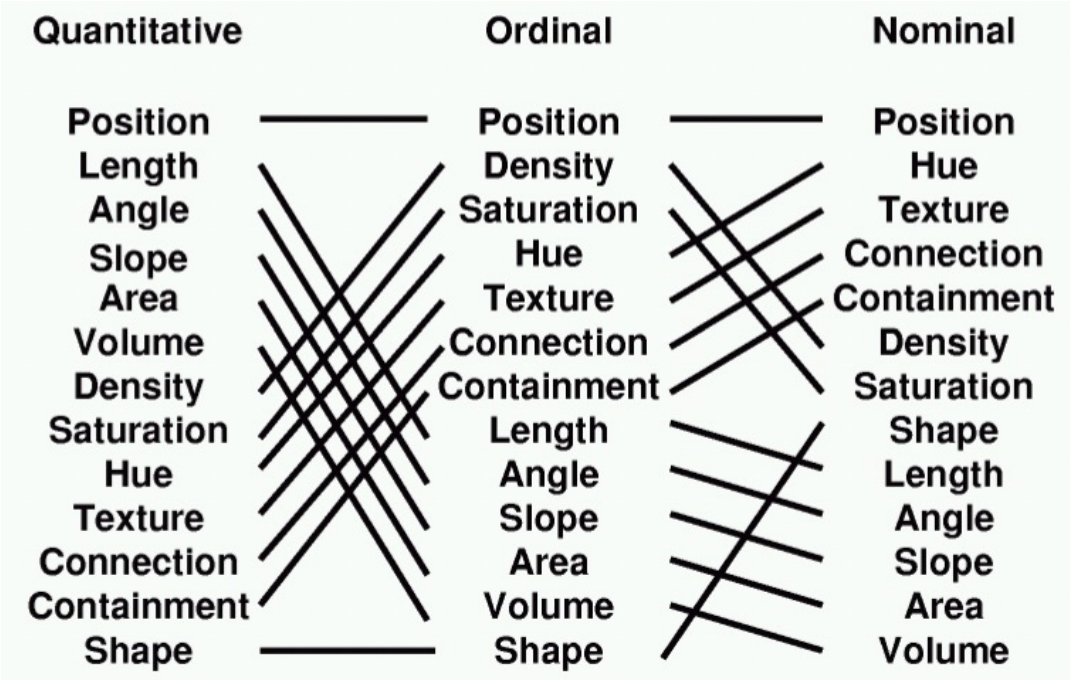
Quantitative

Note: **Q** ⊂**O** ⊂**N**

Mackinlay's Ranking

- Expanded Bertin's variables and conjectured effectiveness of encodings by data type.

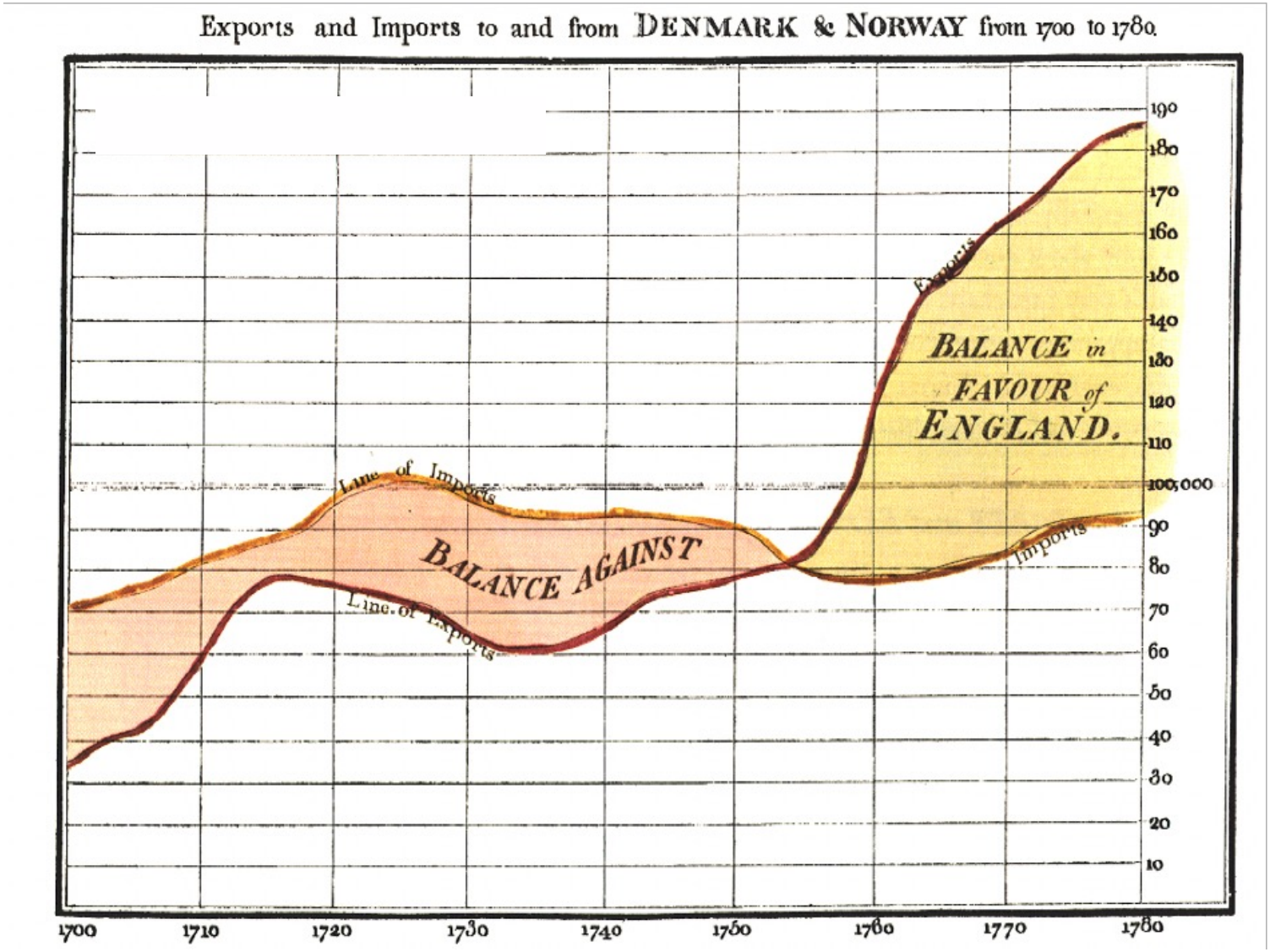
[Mackinlay 86]



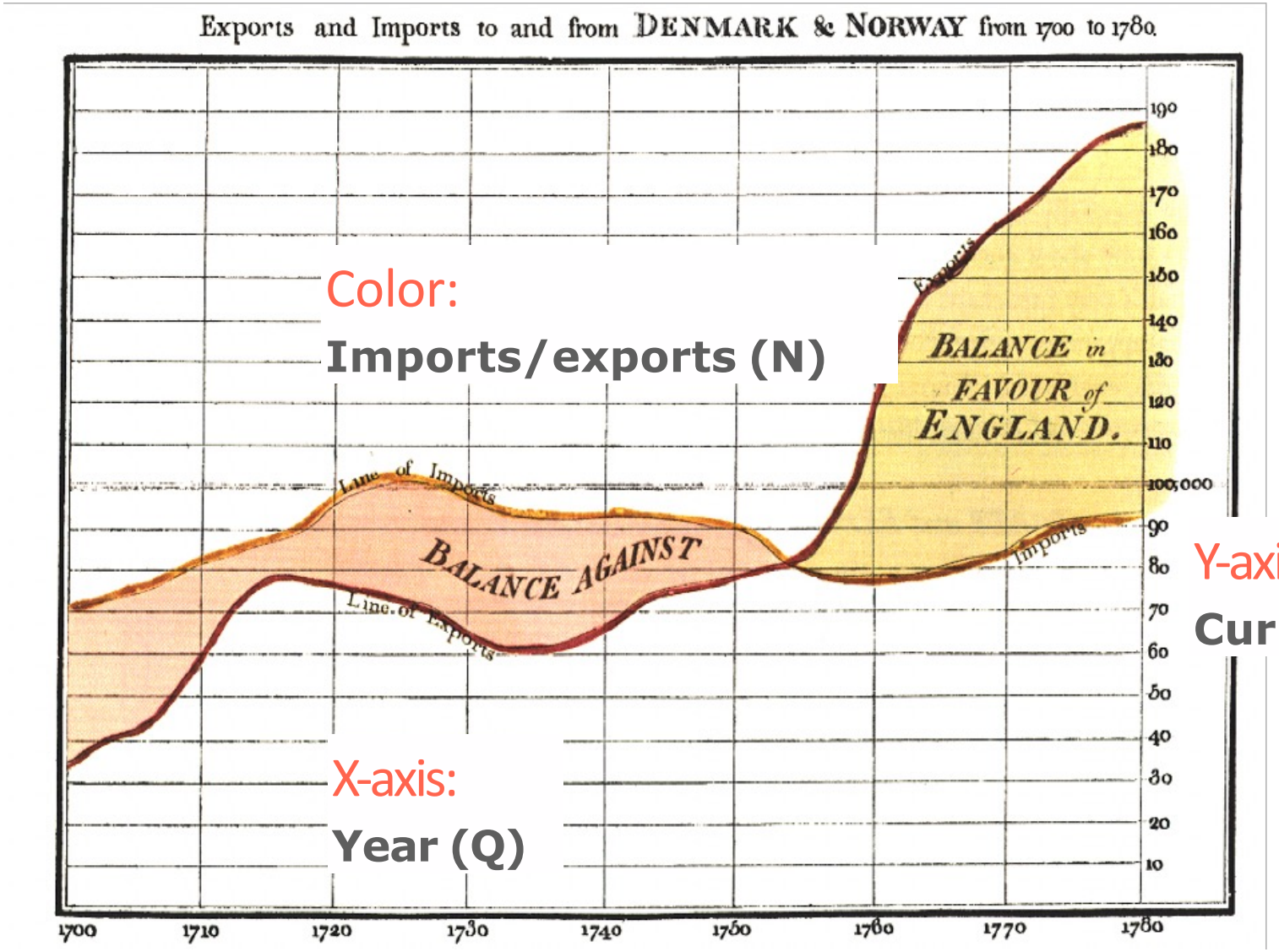
Jock D. Mackinlay
Vice President
Tableau Software

Example: Deconstructions

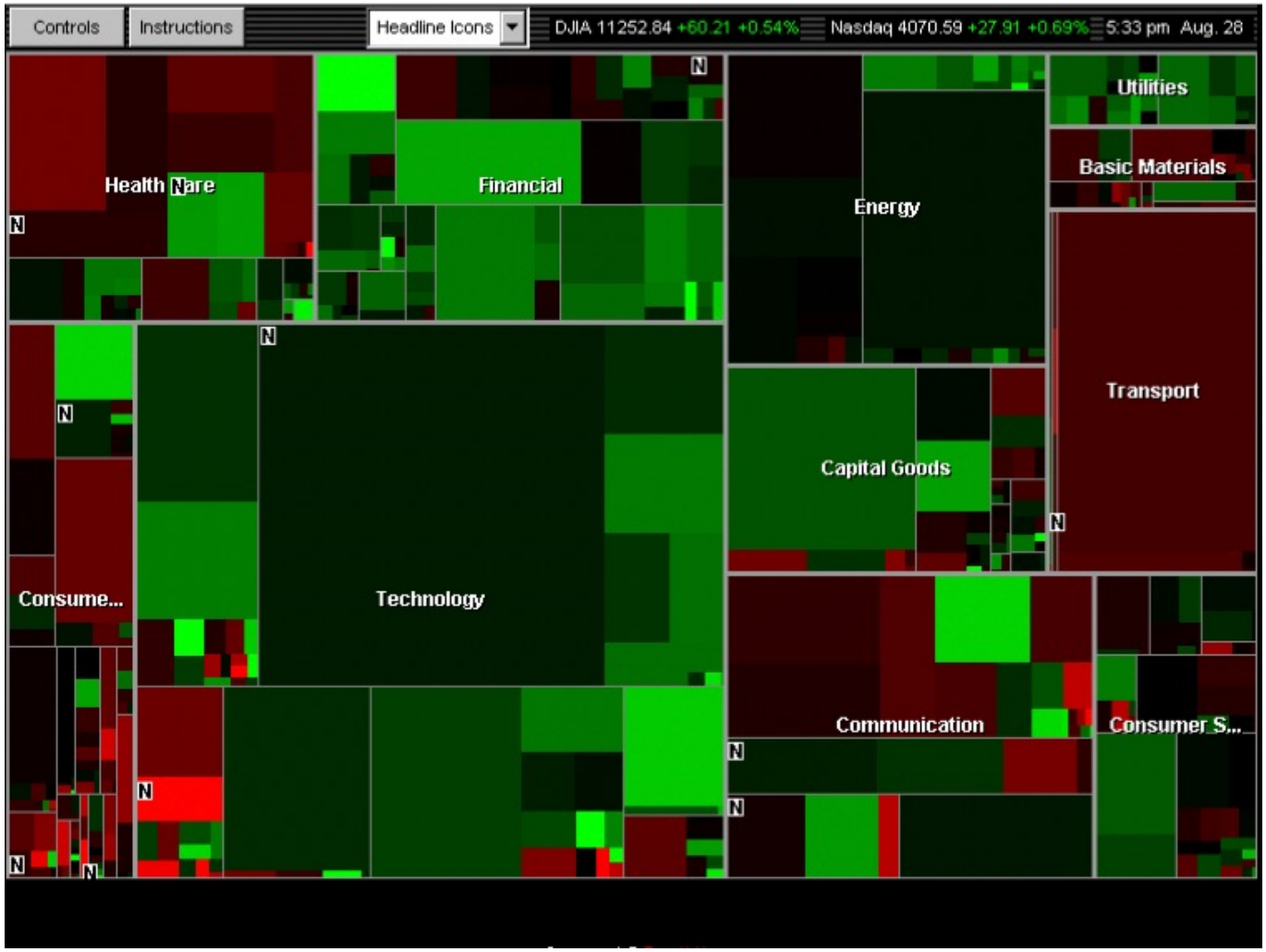
William Playfair, 1786



William Playfair, 1786



Wattenberg's Map of the Market



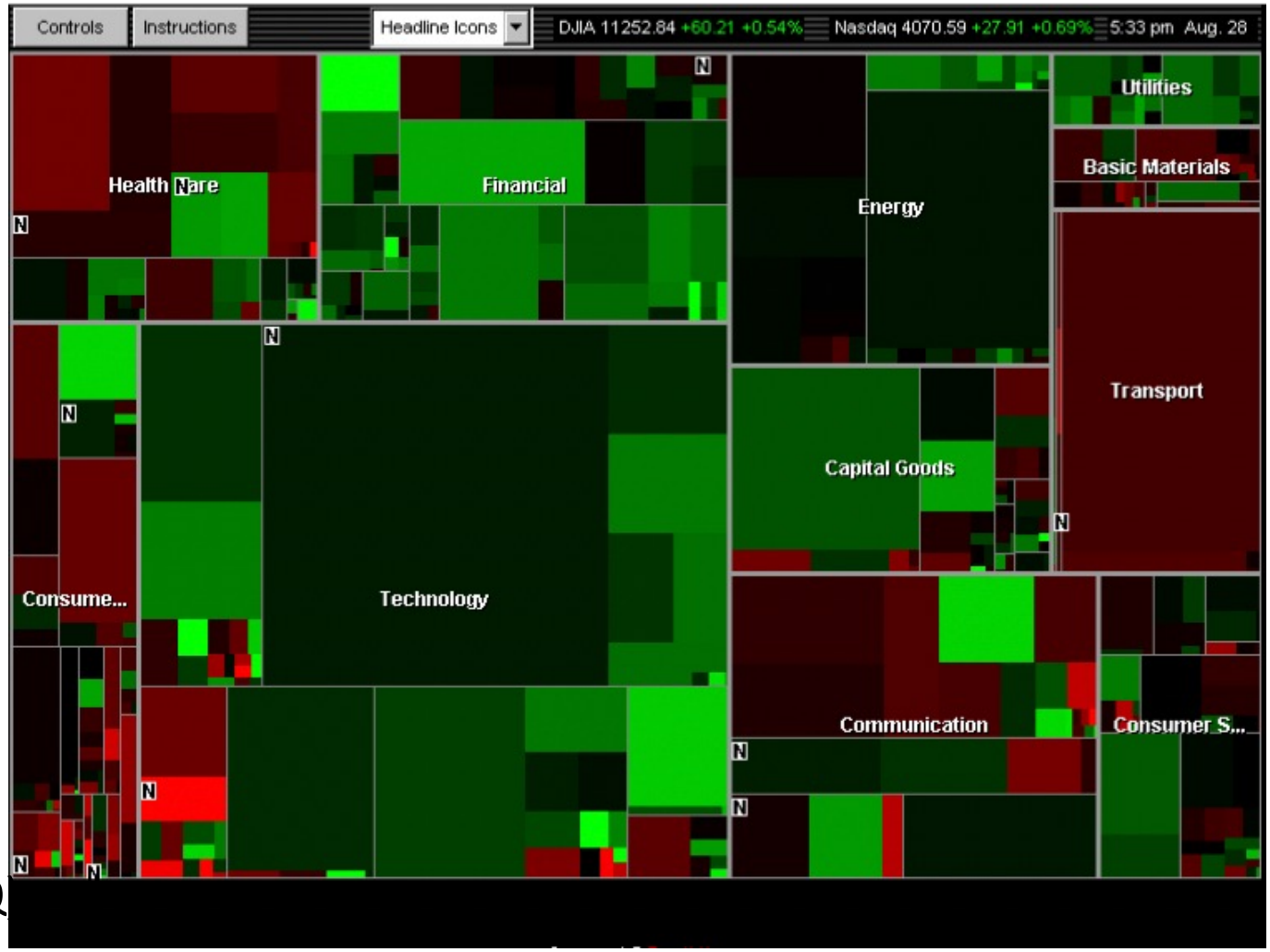
Wattenberg's Map of the Market

Rectangle Area: market cap (Q)

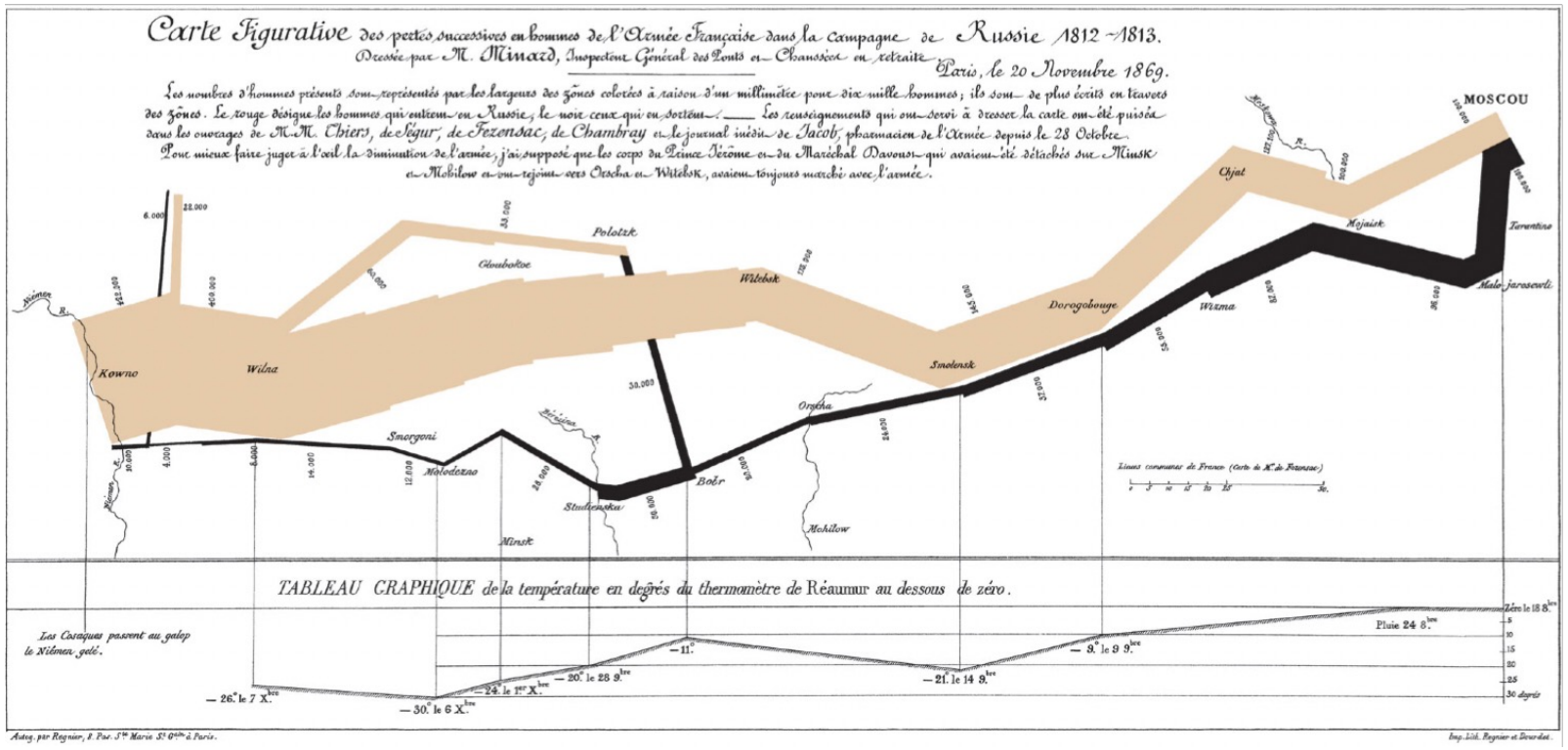
Rectangle Position: market sector (N), market cap (Q)

Color Hue: loss vs. gain (N)

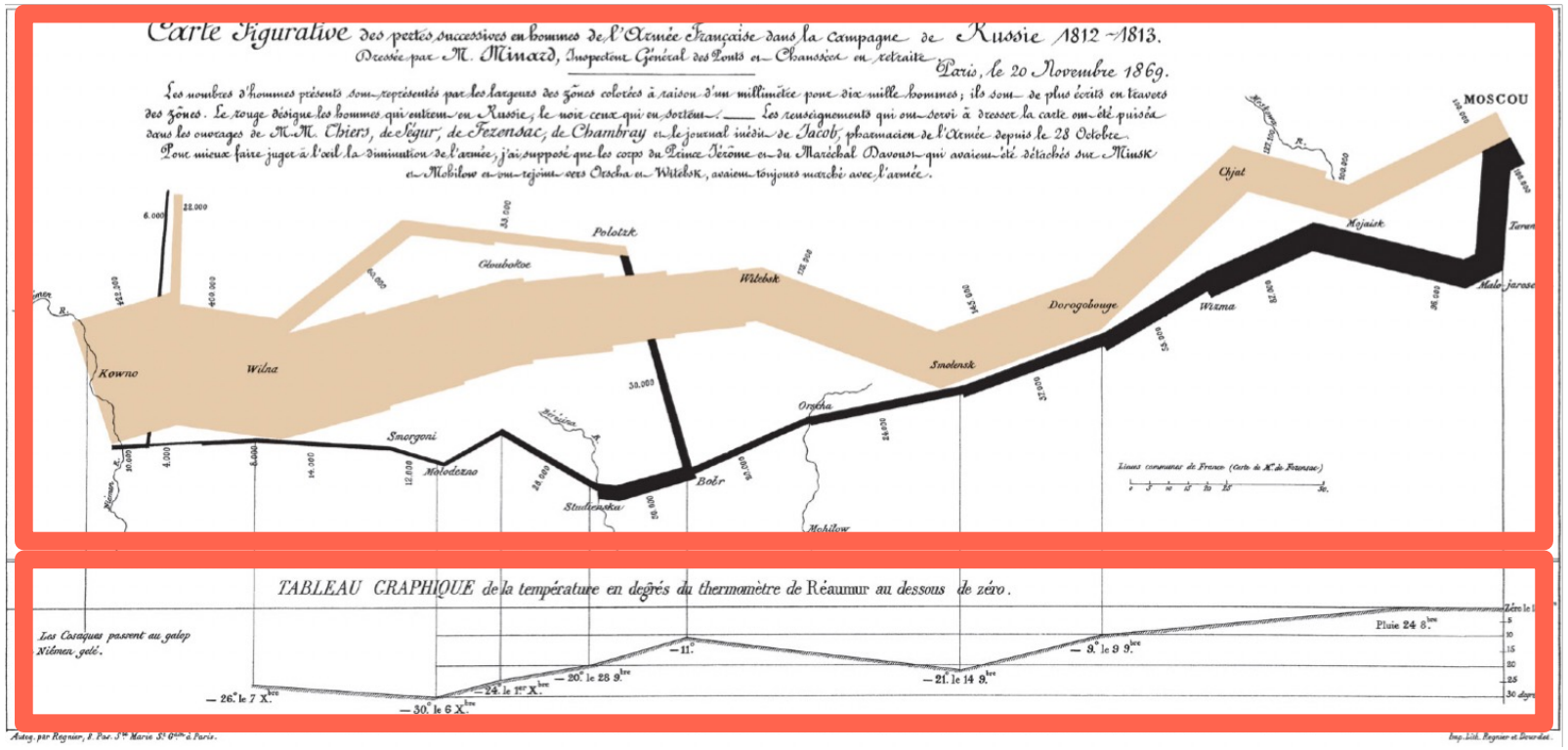
Color Value: magnitude of loss or gain (Q)



Minard 1869: Napoleon's March



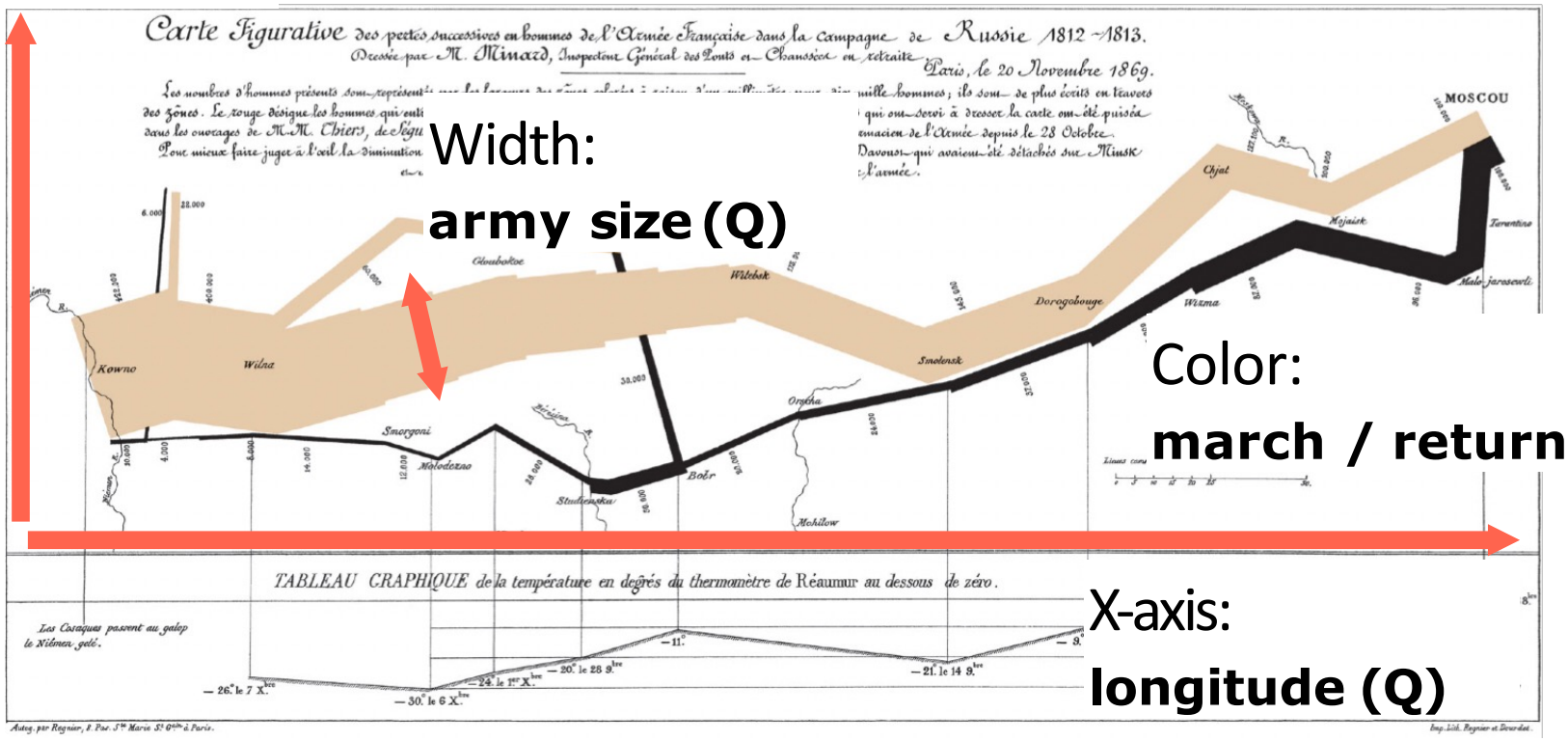
Minard 1869: Napoleon's March



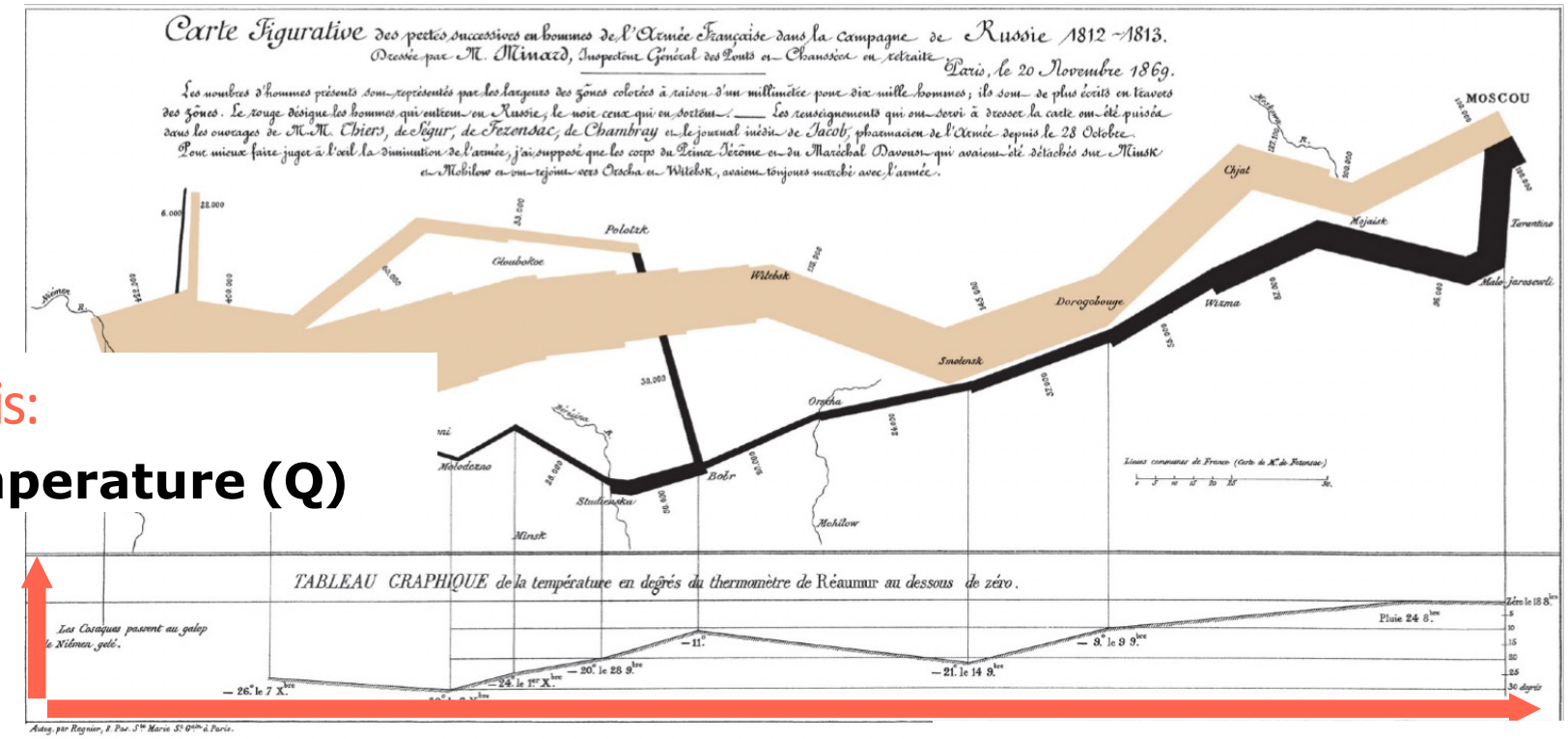
Minard 1869: Napoleon's March

Y-axis:

latitude (Q)



Minard 1869: Napoleon's March



Y-axis:

temperature (Q)

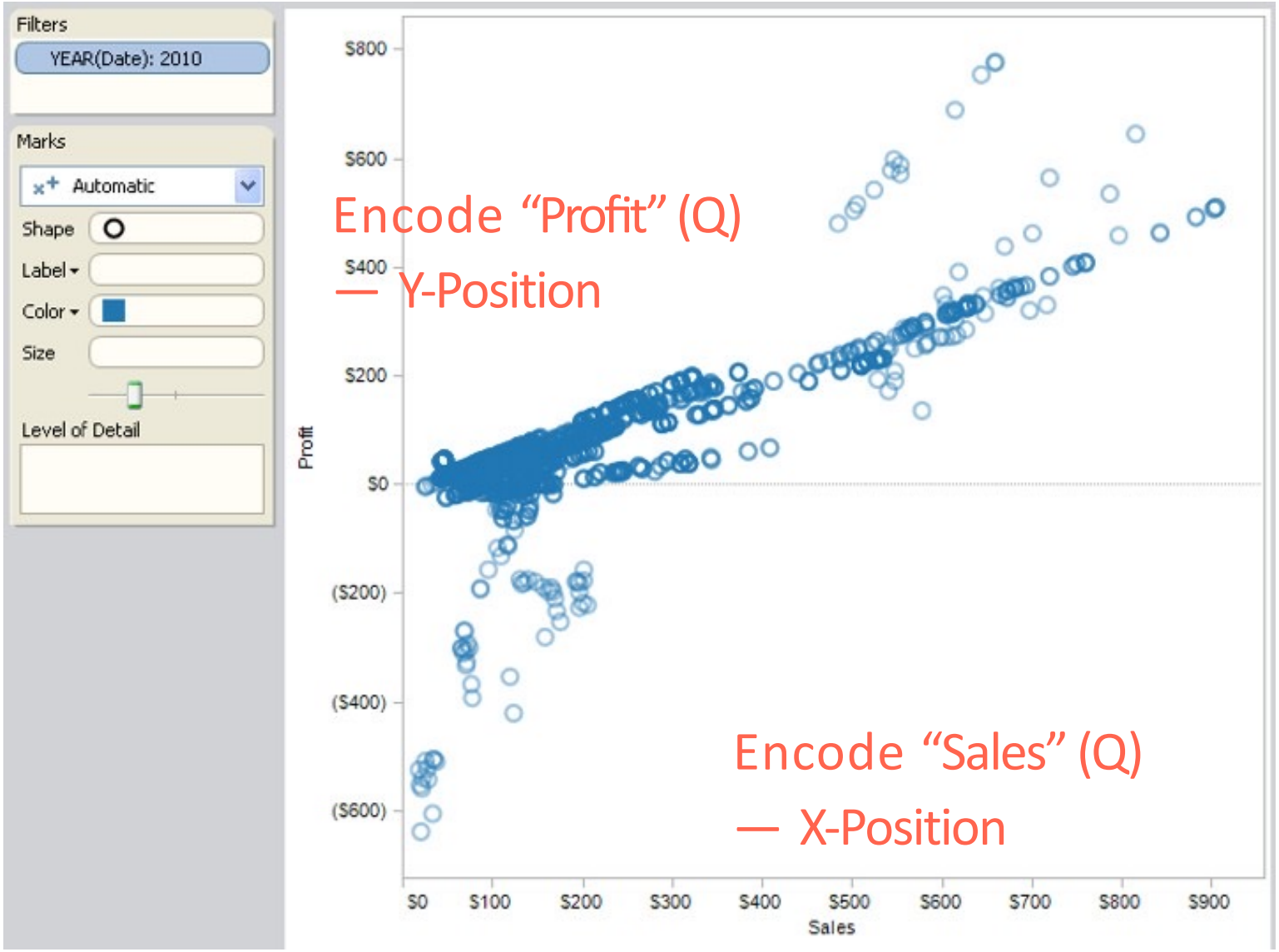
X-axis:

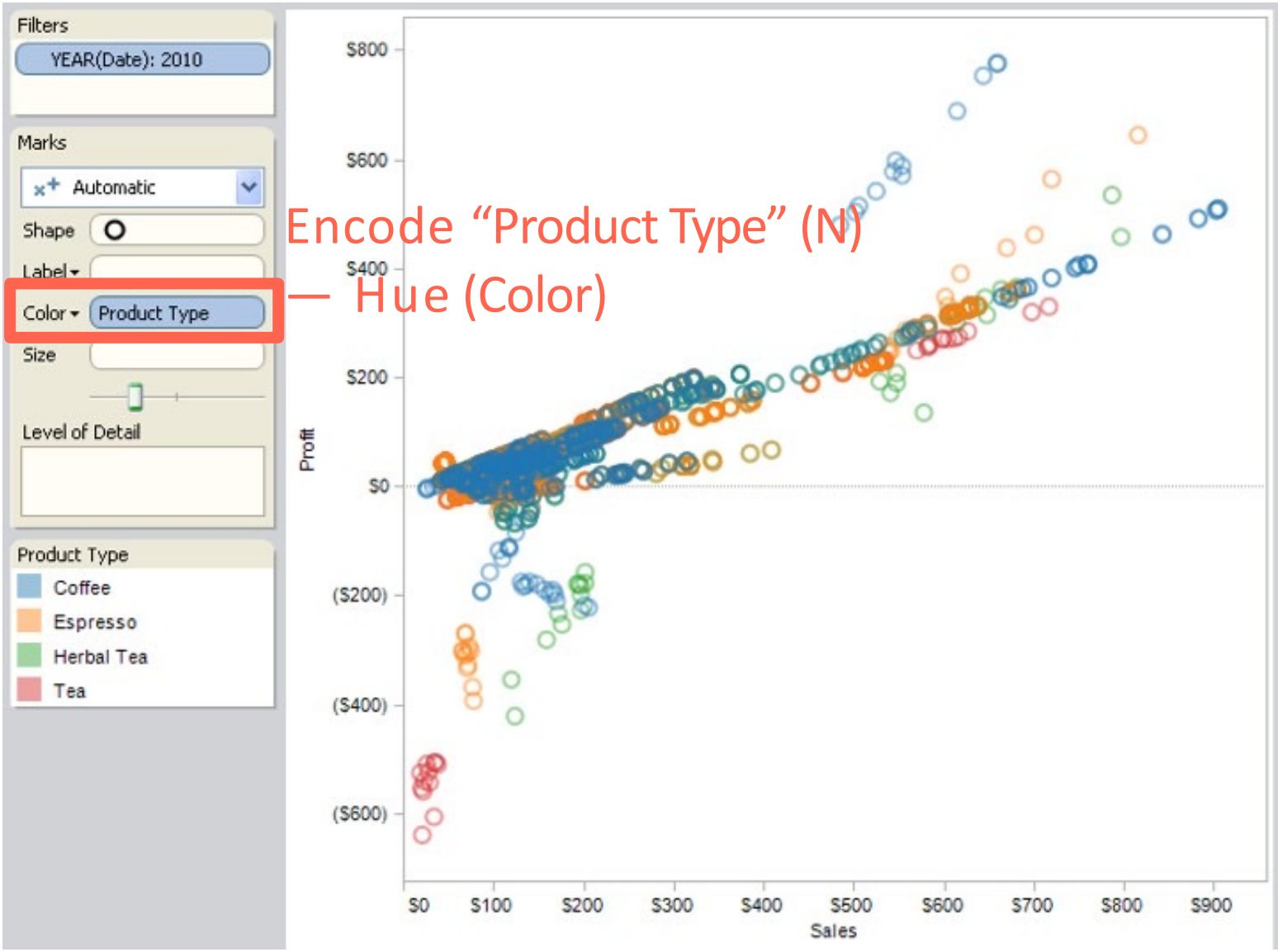
longitude (Q) / time (O)

Example: Encoding Data

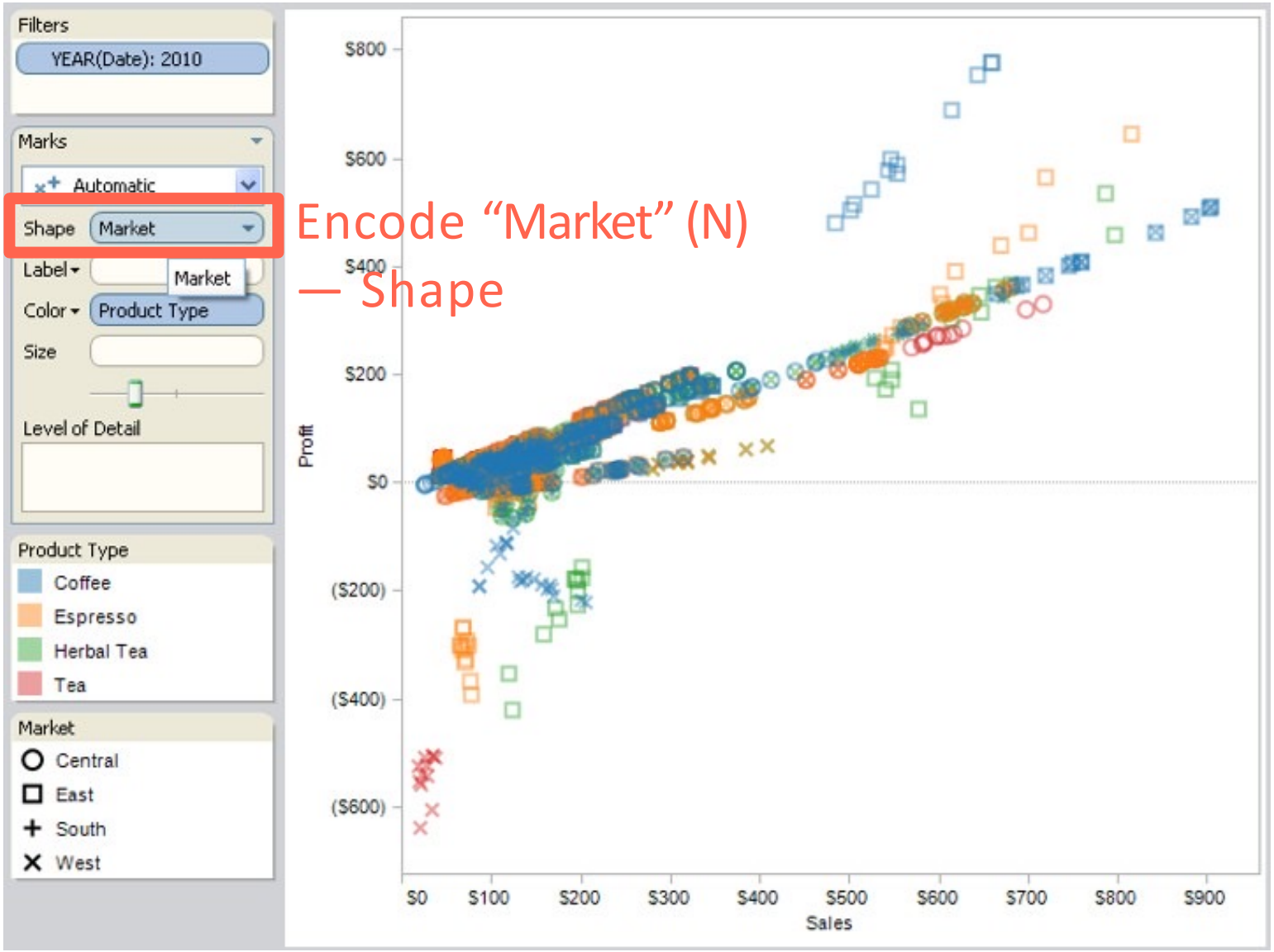
Example: Coffee Sales

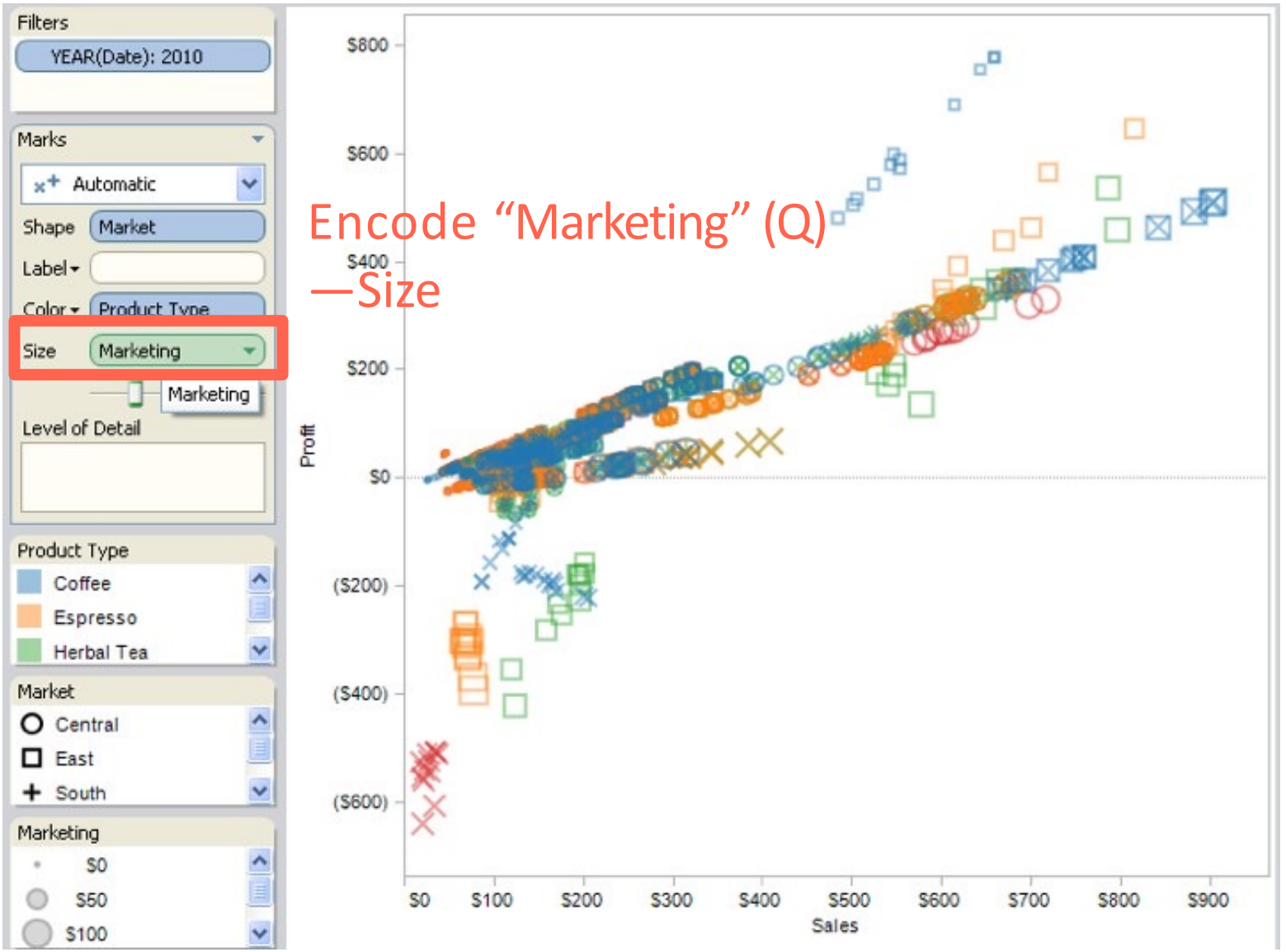
- Sales figures for a fictional coffee chain
  - Sales Q-Ratio
  - Profit Q-Ratio
  - Marketing Q-Ratio
  - Product Type N {Coffee, Espresso, Herbal Tea, Tea}
  - Market N {Central, East, South, West}


Filters
YEAR(Date): 2010
Marks
Automatic
Shape
Label
Color
Size
Level of Detail
Encode "Profit" (Q)
— Y-Position
Encode "Sales" (Q)
— X-Position
Profit
$800
$600
$400
$200
$0
($200)
($400)
($600)
$0
$100
$200
$300
$400
$500
$600
$700
$800
$900
Sales



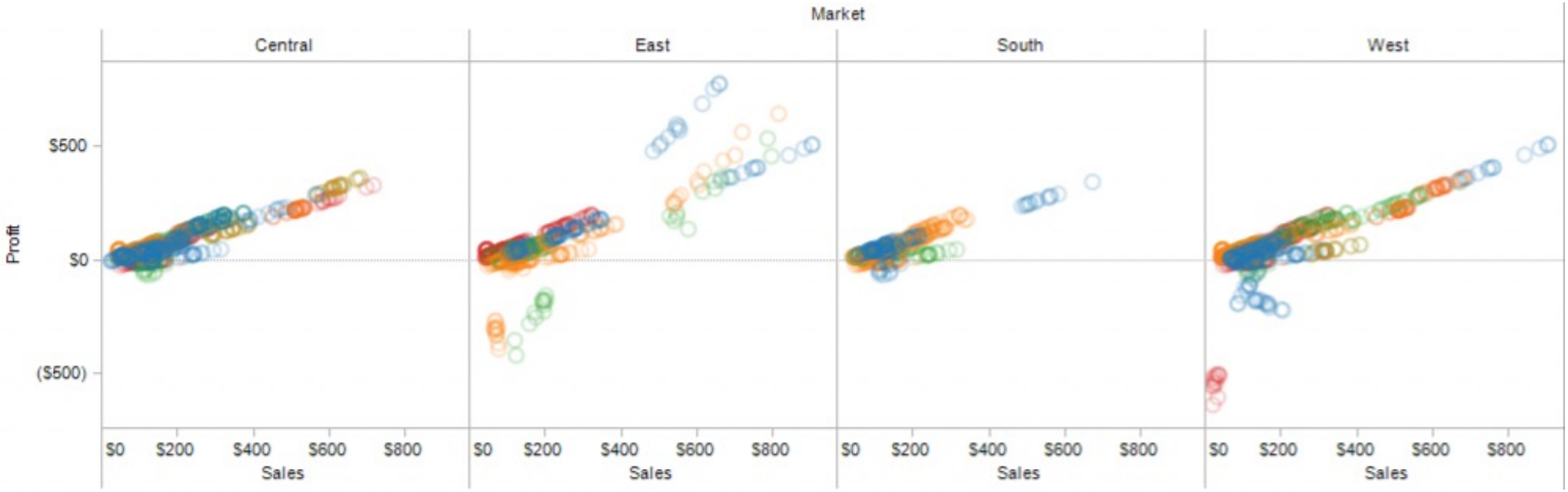
Encode “Product Type” (N)
— Hue (Color)


Filters
YEAR(Date): 2010
Marks
Automatic
Shape
Market
Label
Color
Product Type
Size
Level of Detail
Market
Encode “Market” (N)
— Shape
Product Type
Coffee
Espresso
Herbal Tea
Tea
Market
Central
East
South
West
$800
$600
$400
$200
$0
($200)
($400)
($600)
Profit
$0
$100
$200
$300
$400
$500
$600
$700
$800
$900
Sales


Filters
YEAR(Date): 2010
Marks
Automatic
Shape
Market
Label
Color
Product Type
Size
Marketing
Marketing
Level of Detail
Product Type
Coffee
Espresso
Herbal Tea
Market
Central
East
South
Marketing
$0
$50
$100
Encode “Marketing” (Q)
—Size
$800
$600
$400
$200
$0
($200)
($400)
($600)
Profit
$0
$100
$200
$300
$400
$500
$600
$700
$800
$900
Sales

Avoid over-encoding

- Use trellis plots (small multiples/facets) that subdivide space to enable comparison across multiple plots.



Visual encoding

Choosing visual encodings

- Assume ***k*** visual channels and ***n*** data attributes. We would like to pick the “best” encoding among a combinatorial set of possibilities of size $\mathbf{n^k}$

Choosing visual encodings

- Assume ***k*** visual encodings and ***n*** data attributes. We would like to pick the "best" encoding among a combinatorial set of possibilities of size $\mathbf{n^k}$

- **Principle of Consistency**
  - The properties of the image (visual variables) should match the properties of the data.

- **Principle of Importance Ordering**
  - Encode the most important information in the most effective way.

Design Criteria [Mackinlay 86]

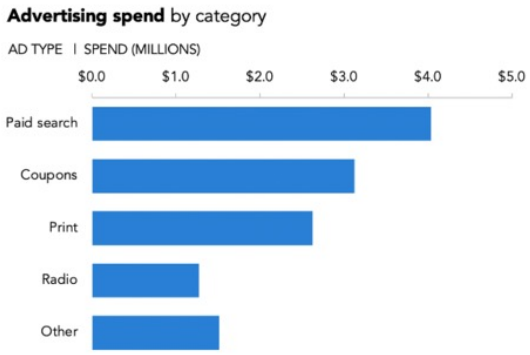
- Expressiveness
- Effectiveness

Design Criteria [Mackinlay 86]

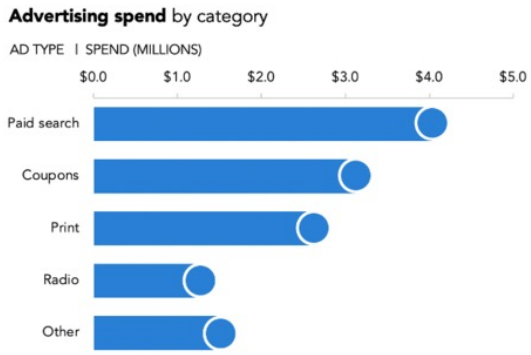
- Expressiveness
  - A set of facts is expressible in a visualization if it expresses all the facts and only the facts in the data.
  - Tell the truth and nothing but the truth
    - (don’t lie, and don’t lie by omission)

Dot plot

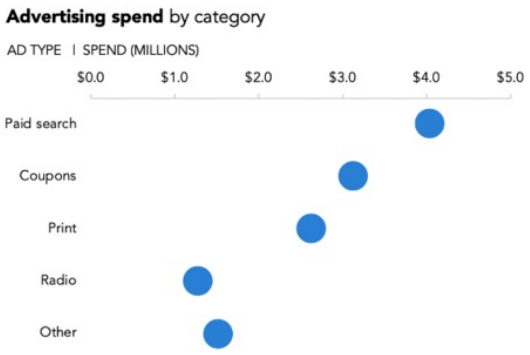
A typical horizontal bar chart…



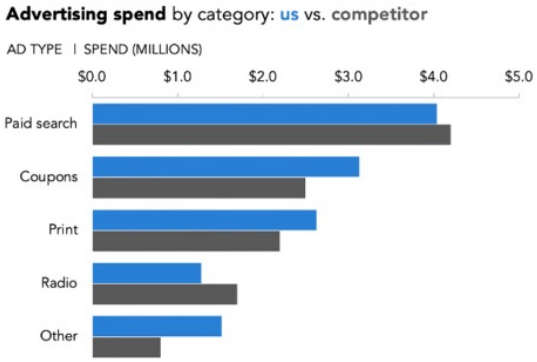
Encode end points with dots.



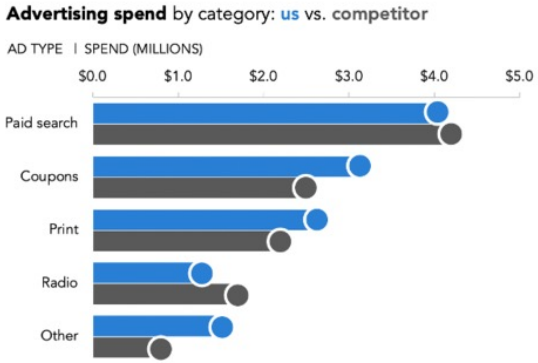
Remove the bars. Voila! A dot plot.



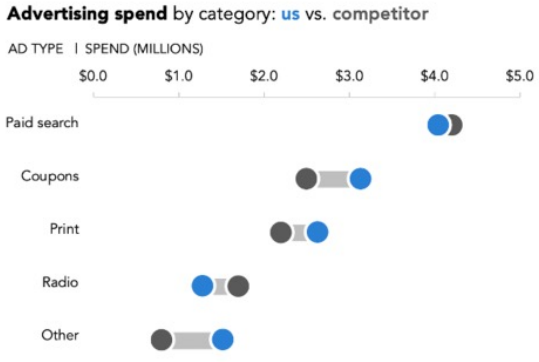
A dual-series bar chart…



Encode end points with dots.

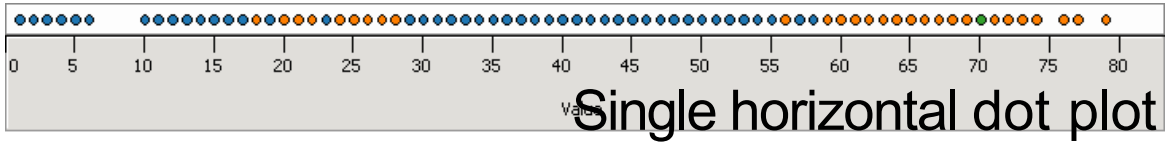


Collapse, remove bars, connect.



Can not express the facts

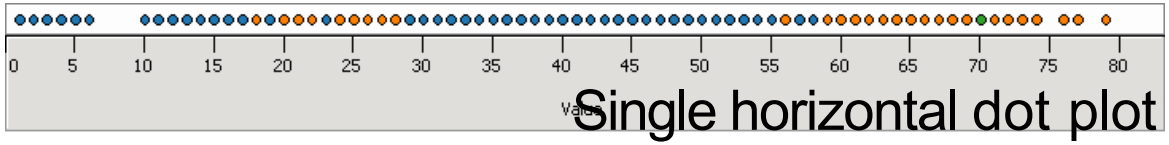
The relationship among multiple data attributes may not be expressed in a single horizontal dot plot.



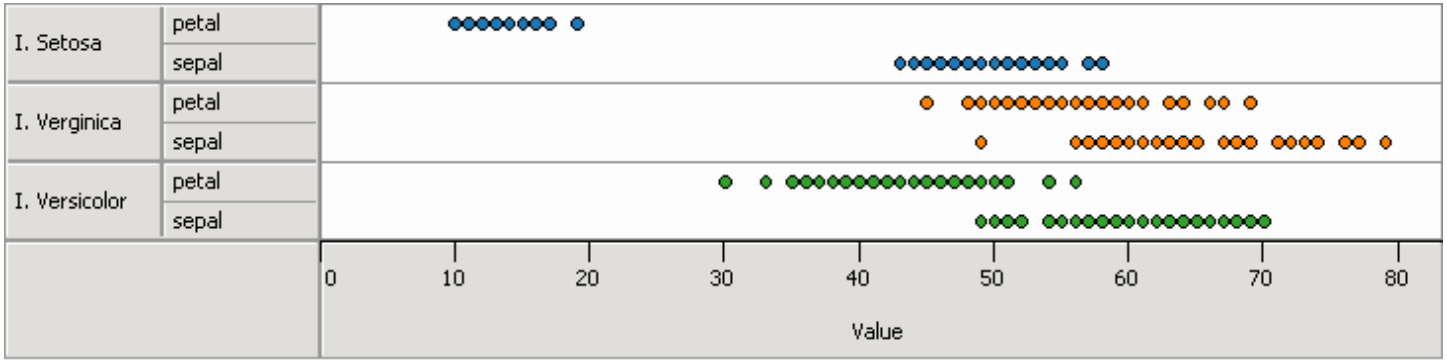
Single horizontal dot plot

Can not express the facts

The relationship among multiple data attributes may not be expressed in a single horizontal dot plot.



Single horizontal dot plot



Categories in different positions

Expresses facts not in the data

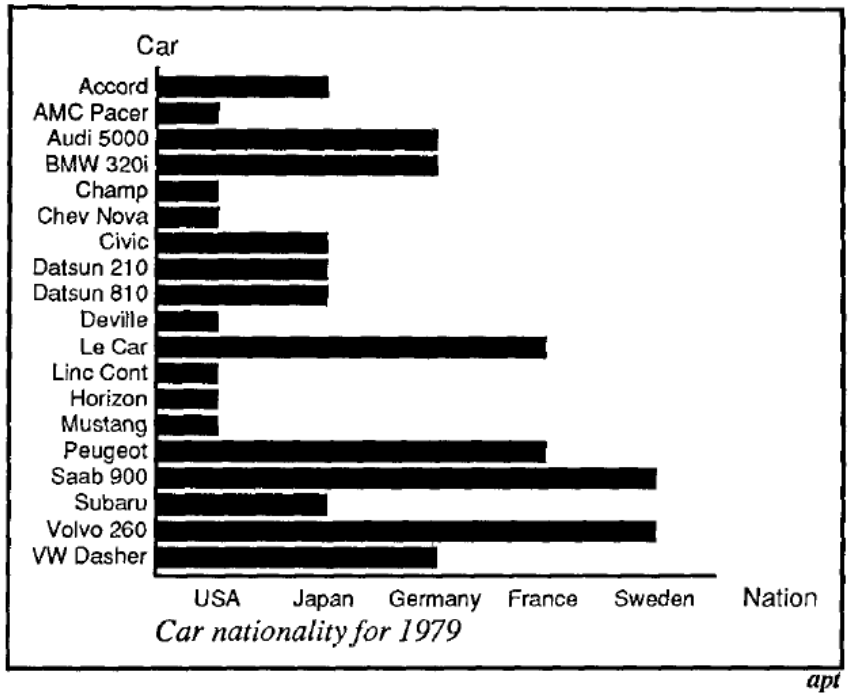


Fig. 11. Incorrect use of a bar chart for the *Nation* relation. The lengths of the bars suggest an ordering on the vertical axis, as if the USA cars were longer or better than the other cars, which is not true for the *Nation* relation.

A length is interpreted as a quantitative value.

Design Criteria [Mackinlay 86]

- Expressiveness
  - A set of facts is expressible in a visualization if it expresses all the facts and only the facts in the data.
  - **Tell the truth and nothing but the truth**
    - **(don't lie, and don't lie by omission)**
- Effectiveness
  - A visualization is more effective than another one if the information conveyed is more readily perceived.
  - **Use encodings that people decode better**
    - **(where better = faster and/or more accurate)**

Mackinlay's Design Algorithm

- APT - "A Presentation Tool", 1986

- User formally specifies data model and type
- **Input**: ordered list of **data variables** to show

- APT searches over design space
  - Test expressiveness of each visual encoding Generate encodings that pass test
  - Rank by perceptual effectiveness criteria

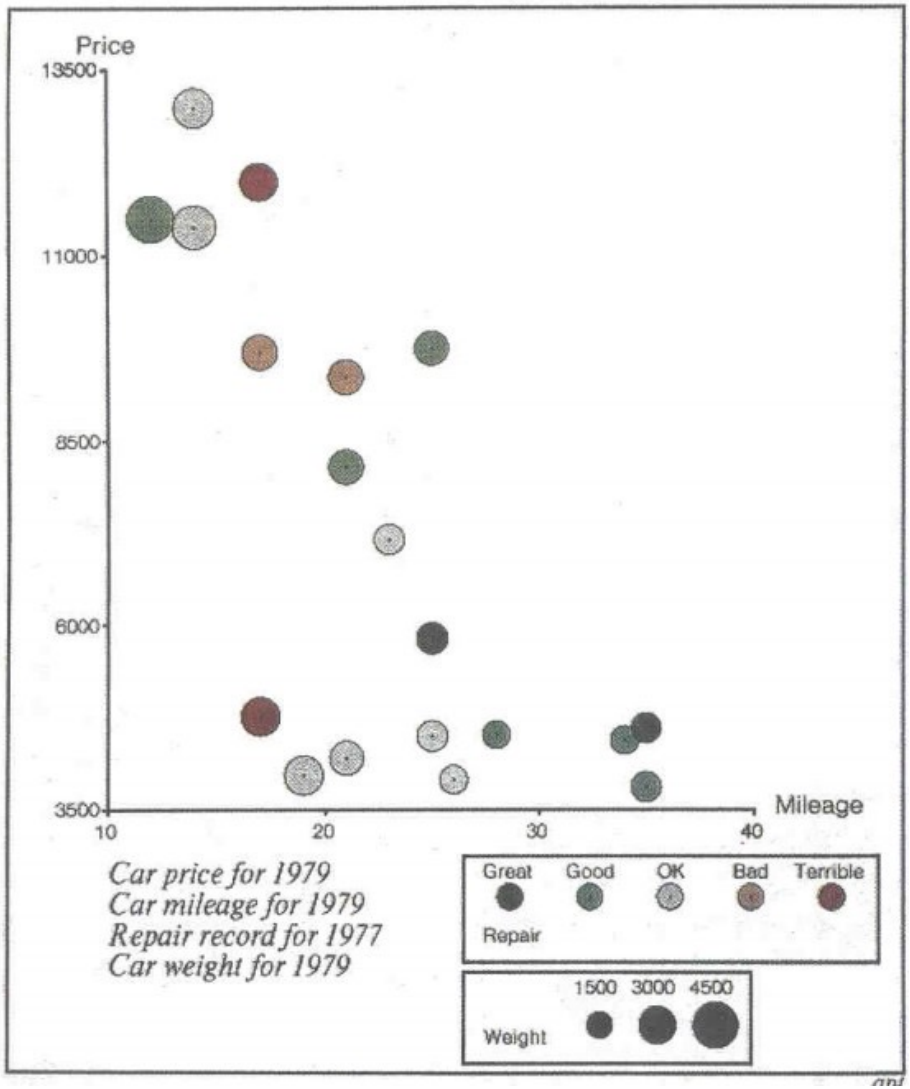
- **Output the "most effective" visualization**

APT

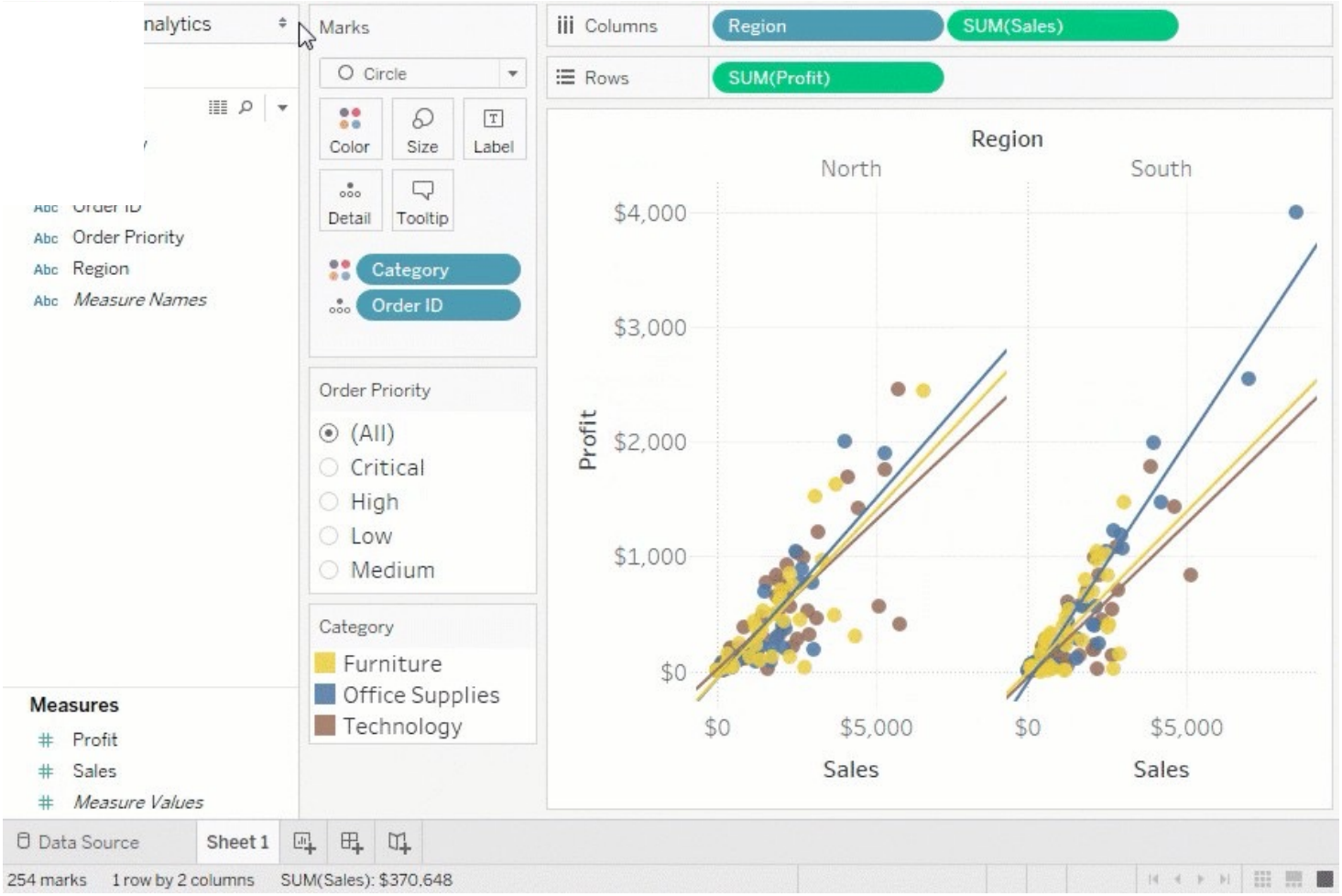
- Automatically generate a chart

for input variables:

1. Price
2. Mileage
3. Repair
4. Weight



Tableau


Marks
Circle
Color
Size
Label
Detail
Tooltip
Category
Order ID
Columns
Region
SUM(Sales)
Rows
SUM(Profit)
Abc Order Priority
Abc Region
Abc Measure Names
Measures
Profit
Sales
Measure Values
Order Priority
(All)
Critical
High
Low
Medium
Category
Furniture
Office Supplies
Technology
Region
North
South
$4,000
$3,000
$2,000
$1,000
$0
Profit
$0
$5,000
Sales
Data Source
Sheet 1
254 marks
1 row by 2 columns
SUM(Sales): $370,648

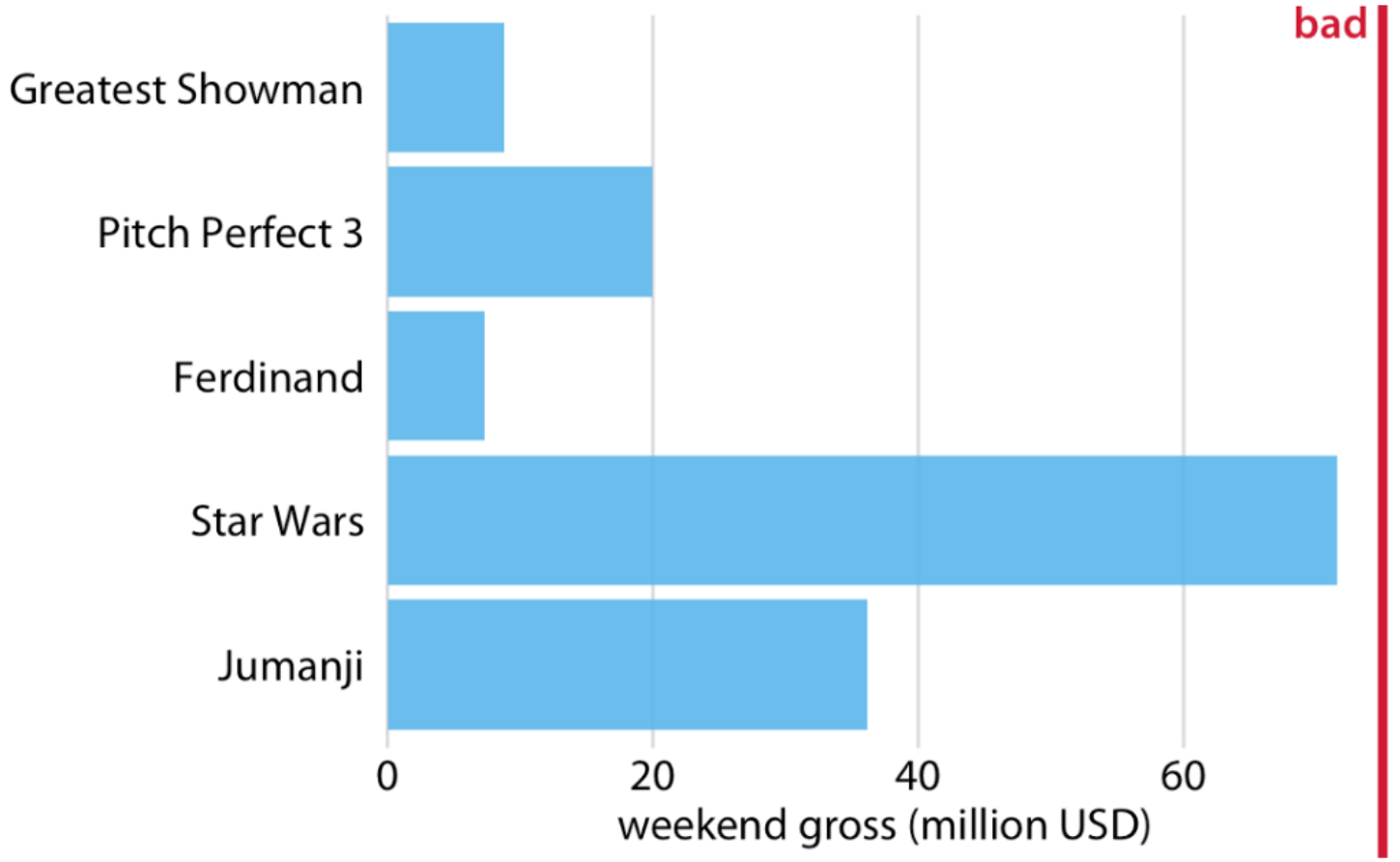
Take away: Visual Encoding Design

- Use expressive and effective encodings
- Avoid over-encoding
  - Reduce the problem space
  - Use interaction to generate relevant views

- *Rarely does a single visualization answer all questions. Instead, the ability to generate appropriate visualizations quickly is critical!*

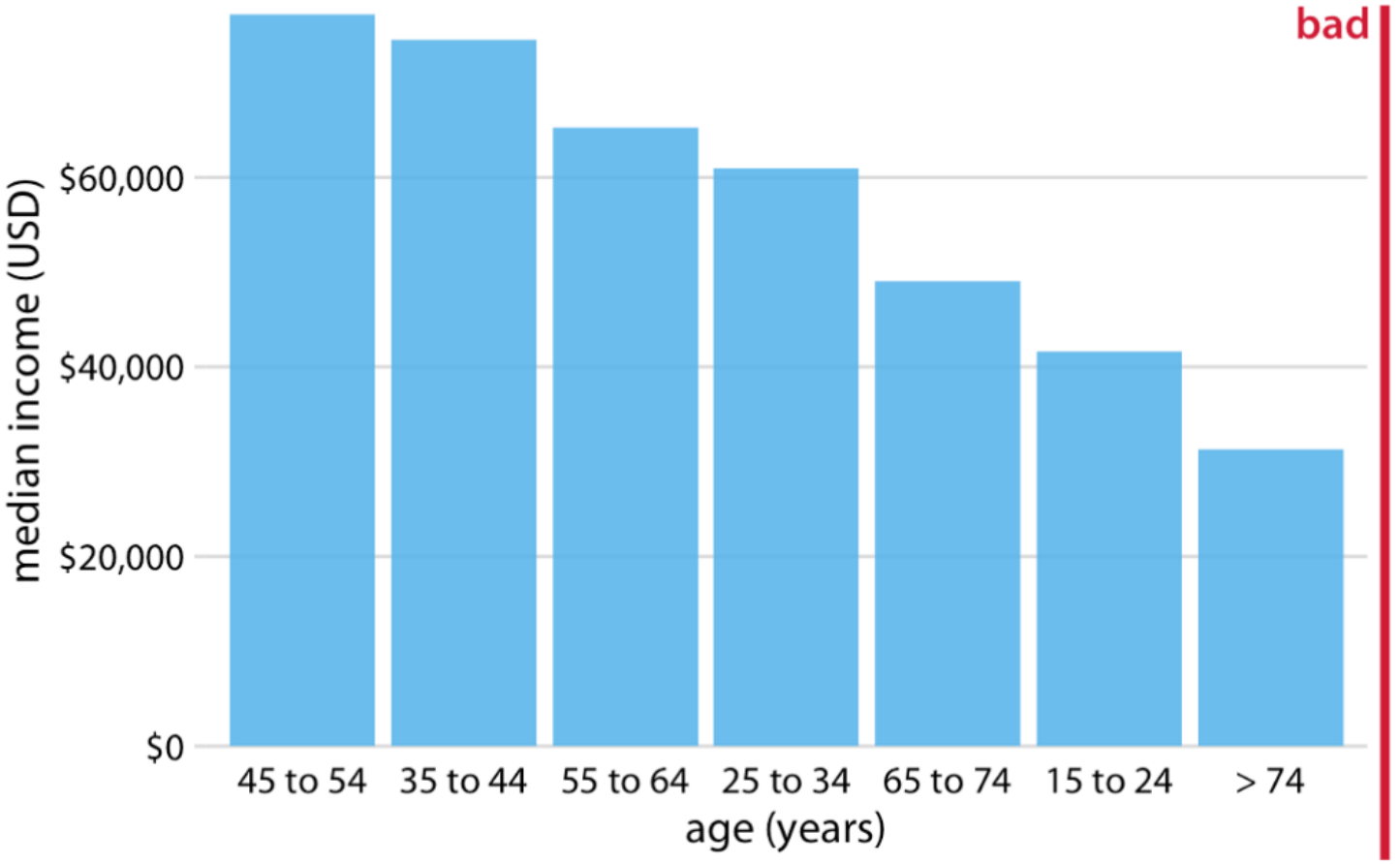
Q1:

Biểu đồ dưới đây gặp vấn đề gì?



Q2

Biểu đồ dưới đây gặp vấn đề gì?



Q3: Biểu đồ dưới đây gặp vấn đề gì?