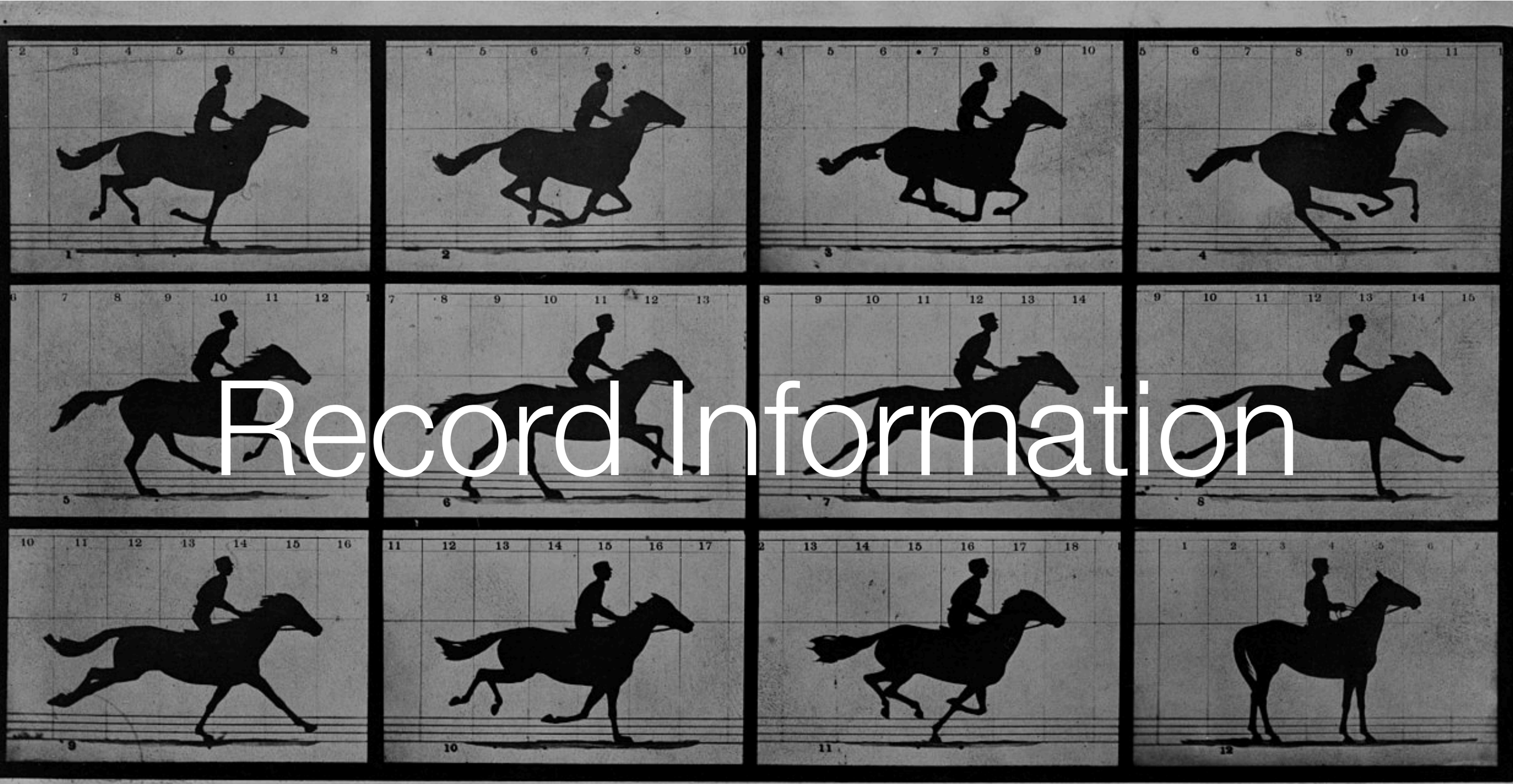
We will start at 2:05 pm!

Thanks for coming early!

Yesterday

Fundamental

1. **Value of visualization**
2. Design principles
3. Graphical perception



Record Information

Copyright, 1878, by MUYBRIDGE.

MORSE'S Gallery, 417 Montgomery St., San Francisco.

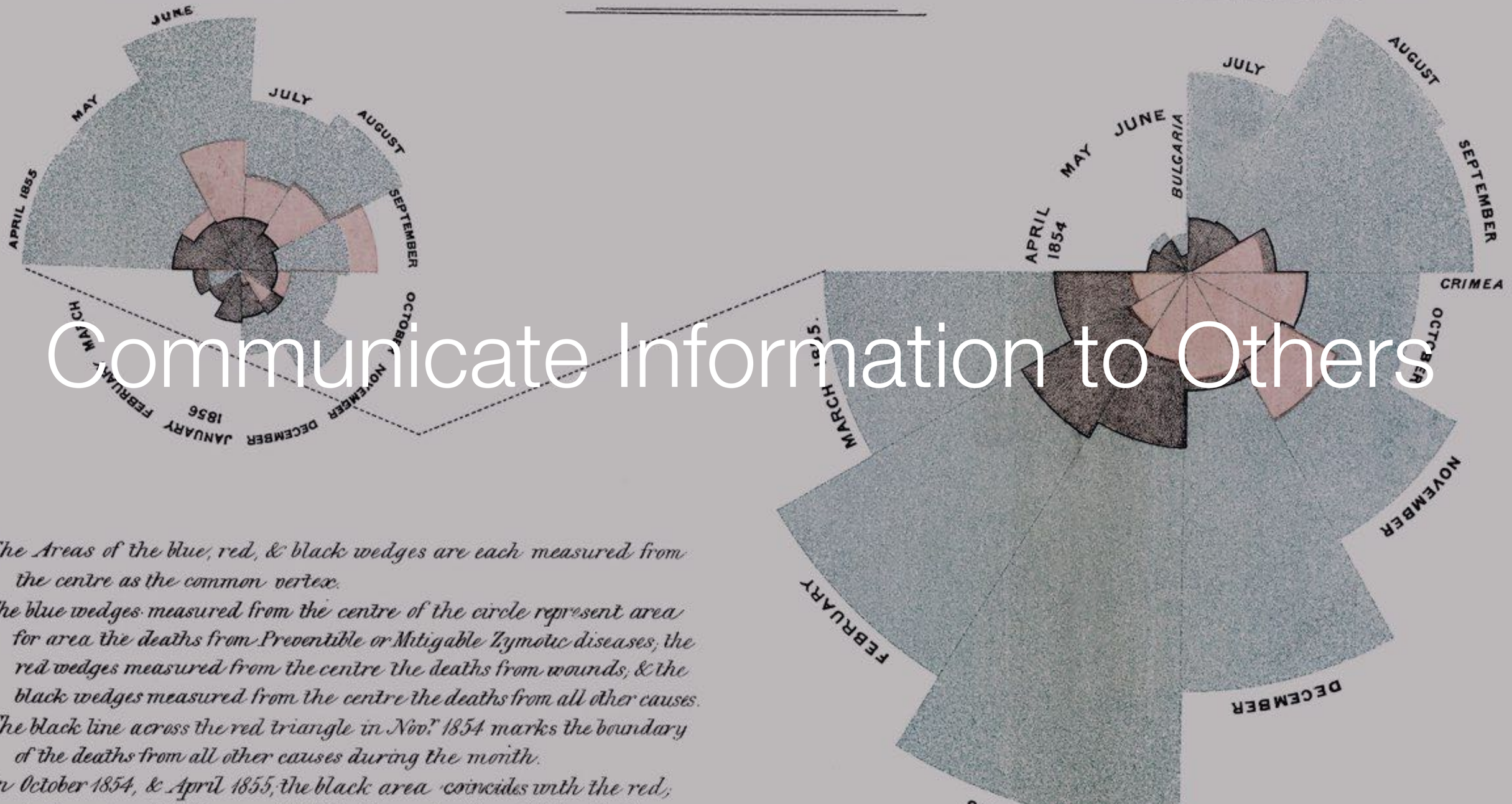
THE HORSE IN MOTION.


Support Analytical Reasoning

DIAGRAM of the CAUSES of MORTALITY IN THE ARMY IN THE EAST.

2.
APRIL 1855 to MARCH 1856.

1.
APRIL 1854 to MARCH 1855.



Communicate Information to Others

The Areas of the blue, red, & black wedges are each measured from the centre as the common vertex.

The blue wedges measured from the centre of the circle represent area for area the deaths from Preventible or Mitigable Zymotic diseases, the red wedges measured from the centre the deaths from wounds, & the black wedges measured from the centre the deaths from all other causes.

The black line across the red triangle in Nov.r 1854 marks the boundary of the deaths from all other causes during the month.

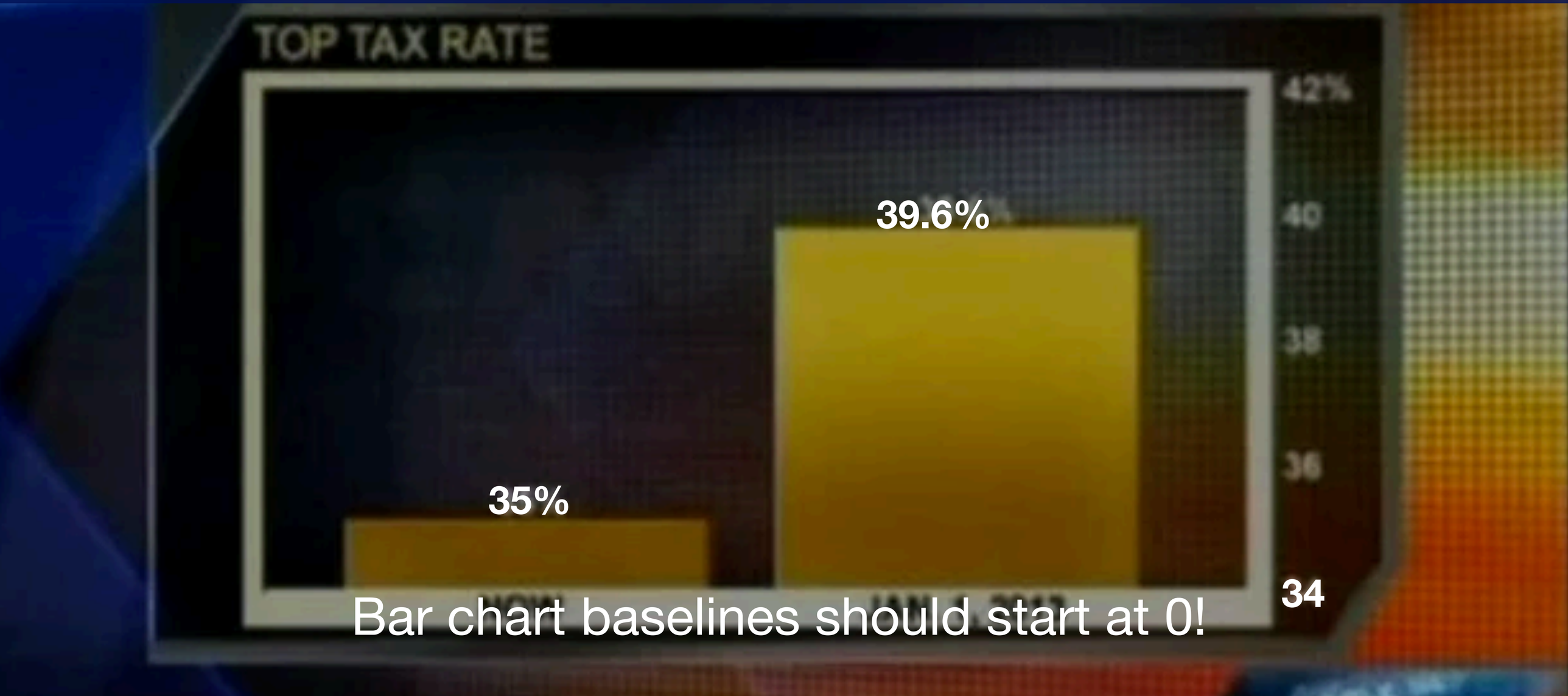
In October 1854, & April 1855, the black area coincides with the red,

Yesterday

Fundamental

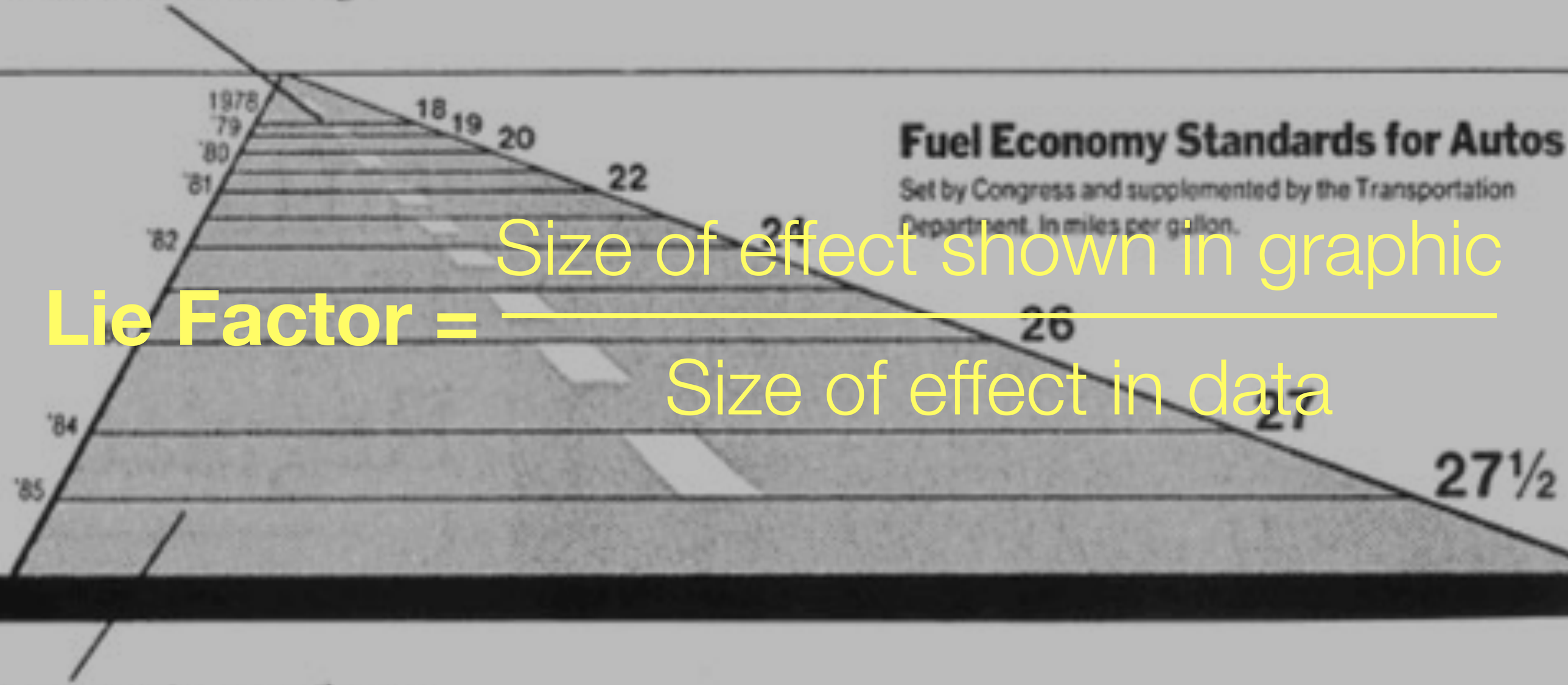
1. Value of visualization
2. **Design principles**
3. Graphical perception

Graphical Integrity



Bar chart baselines should start at 0!

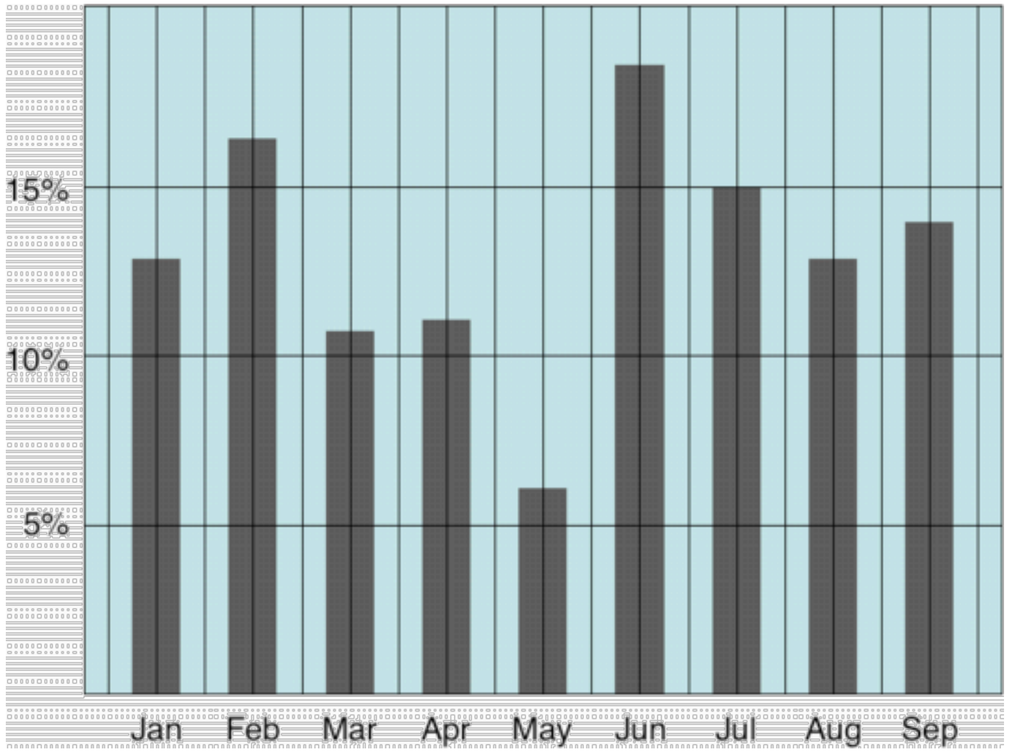
ne, representing 18 miles per
in 1978, is 0.6 inches long.

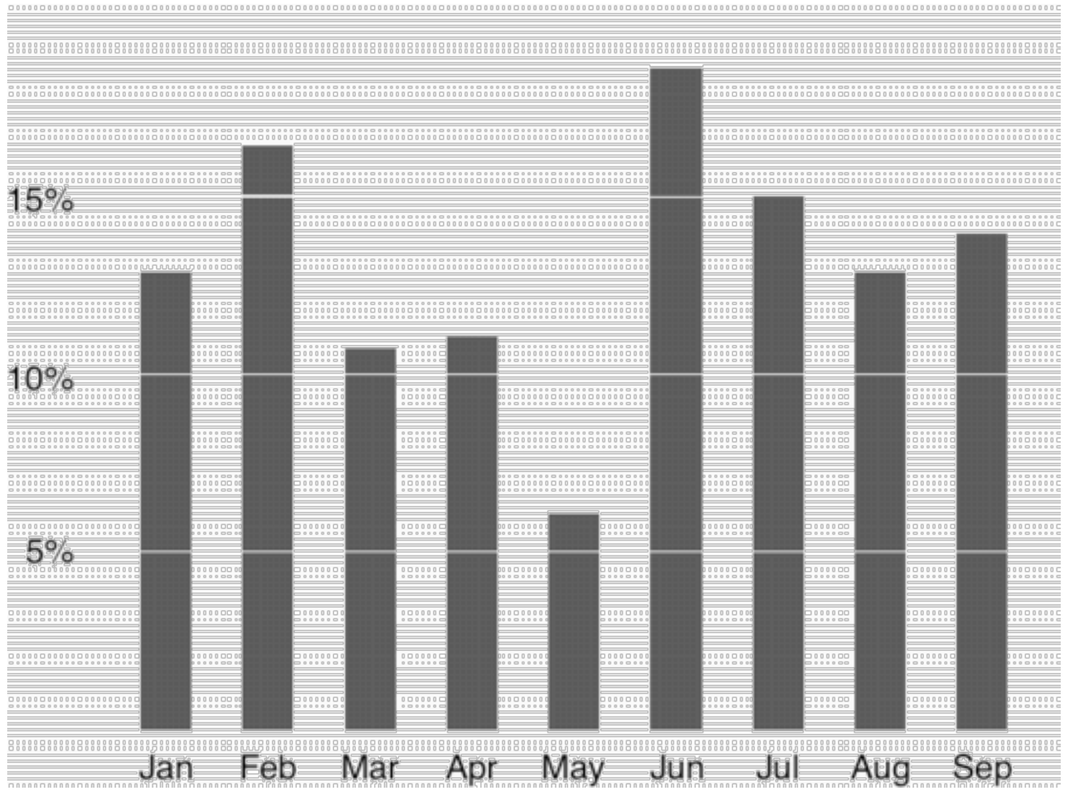


Lie Factor = Size of effect shown in graphic / Size of effect in data

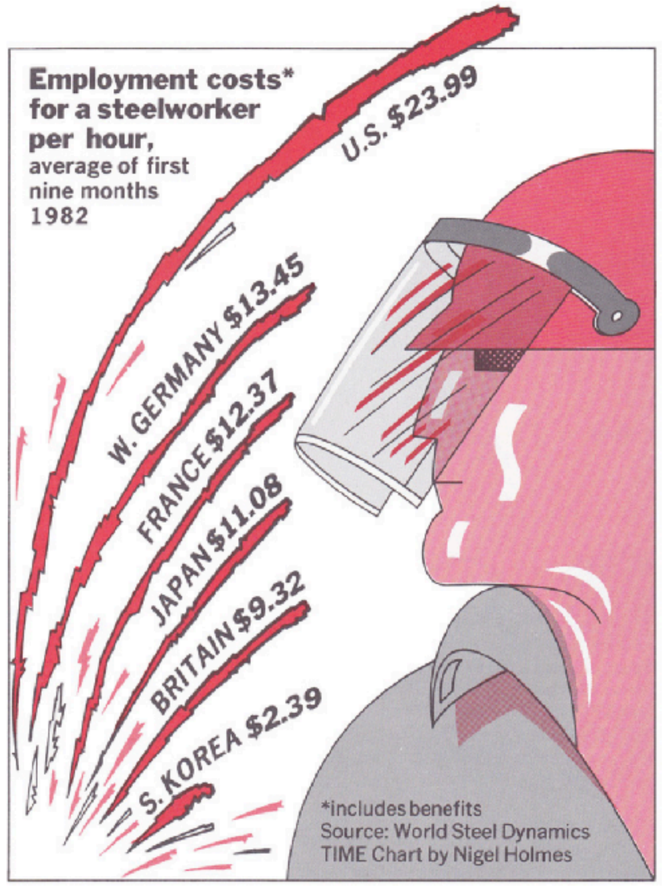
ne, representing 27.5 miles per
in 1985, is 5.3 inches long.

Maximize Data-Ink Ratio

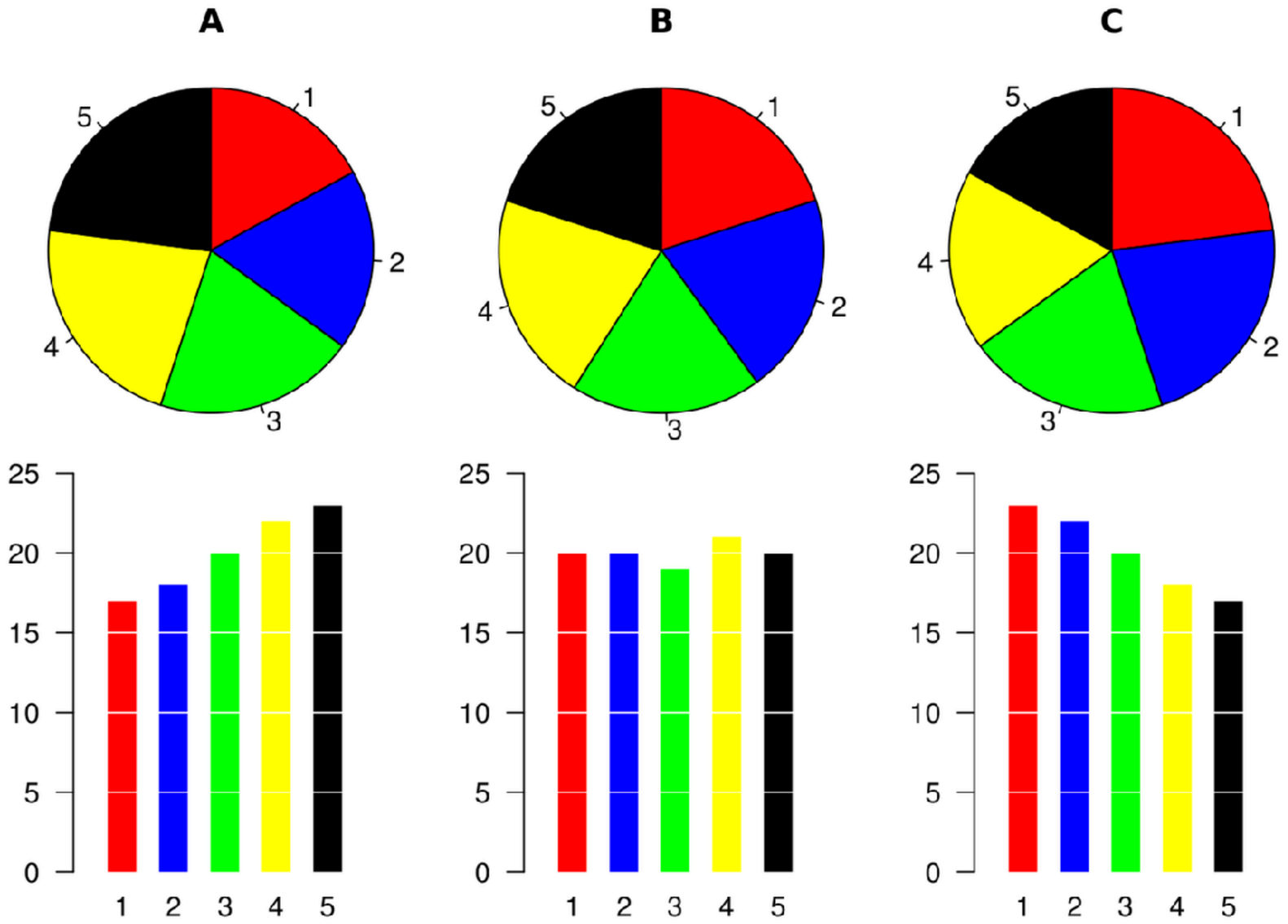




Useful chart junks?

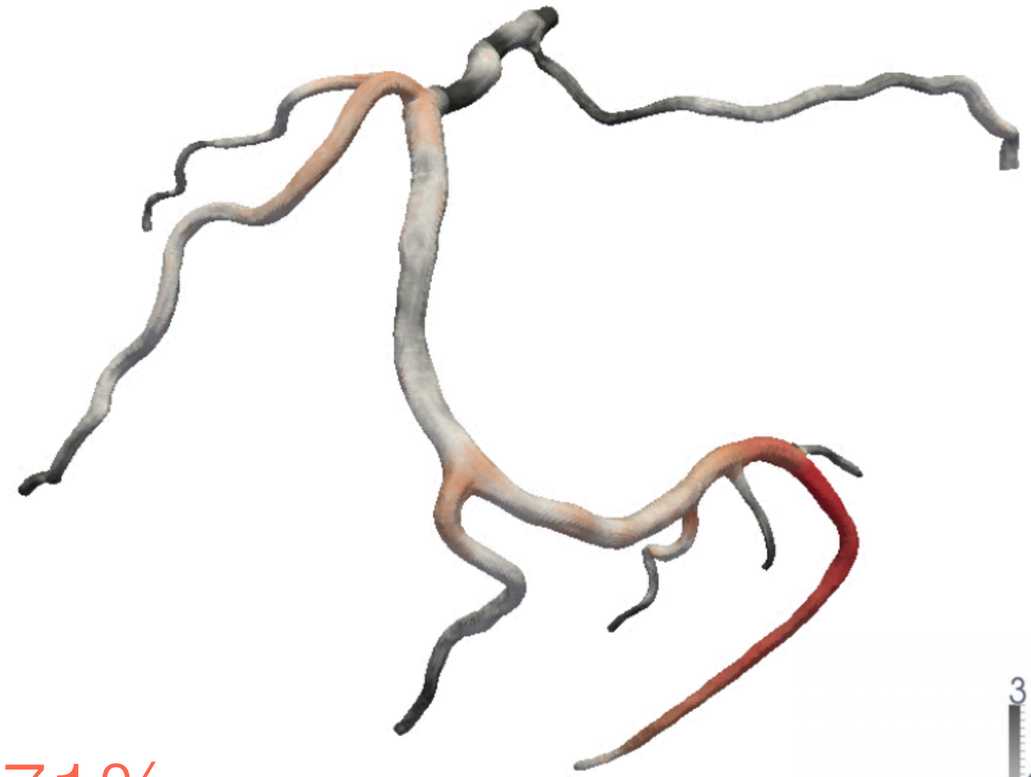


Problem with Pie Charts



World's Most Accurate Pie Chart

Problem with Rainbow Colormap

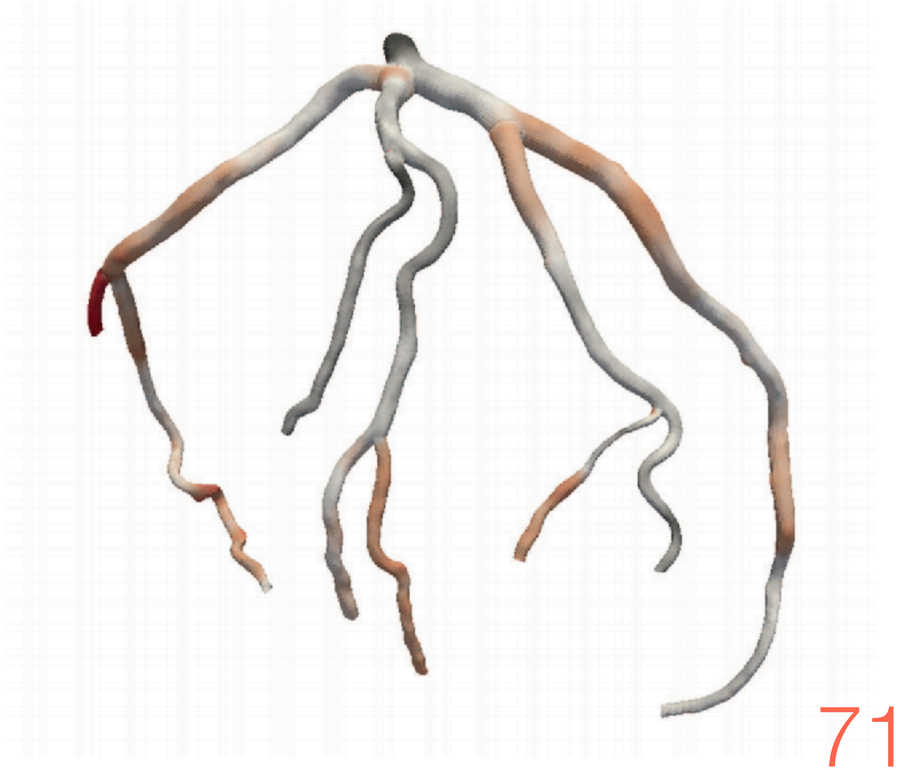


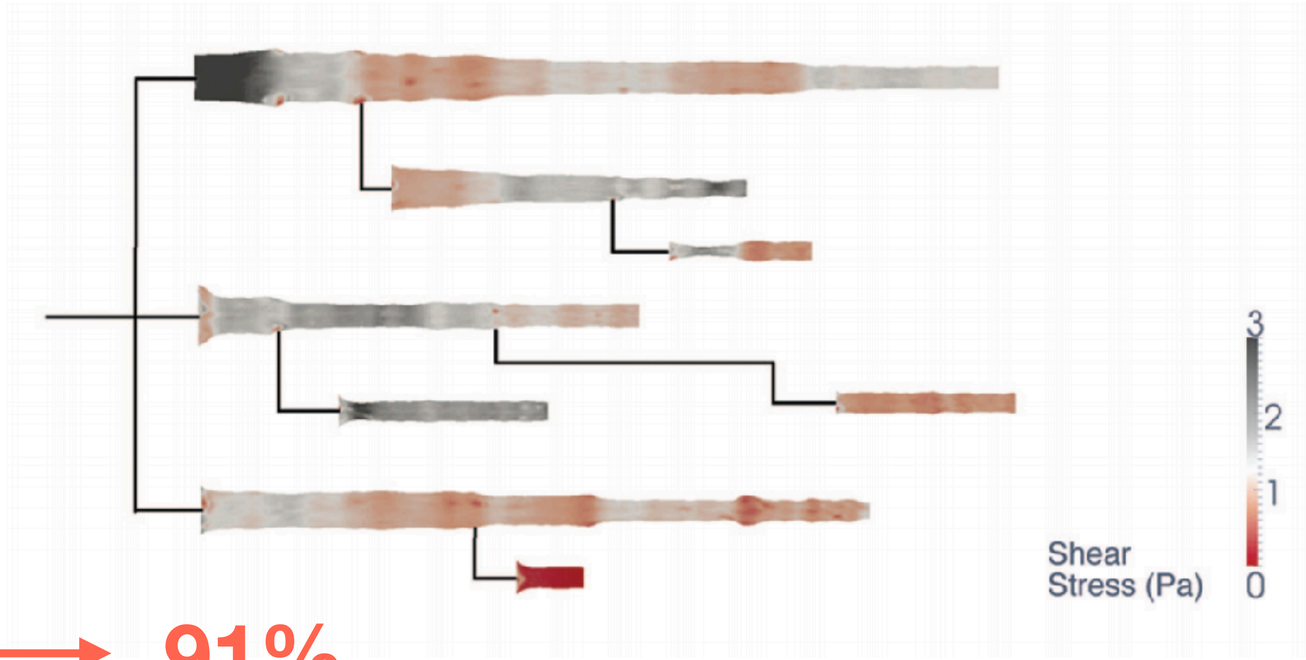
39% → 71%

10.2 sec/region → 5.6 sec/region

[M. Borkin et al 2011]

Problem with 3D Charts





71% → **91%**

5.6 sec/region → **2.4 sec/region**

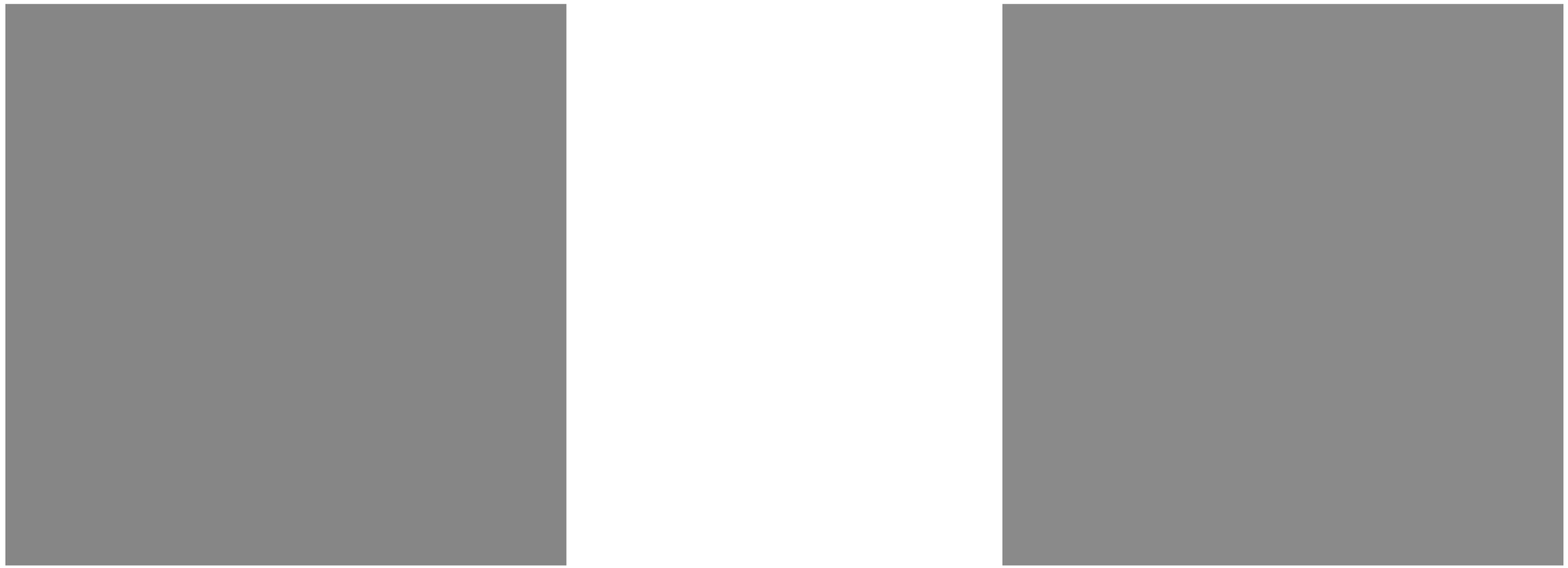
[M. Borkin et al 2011]

Yesterday

Fundamental

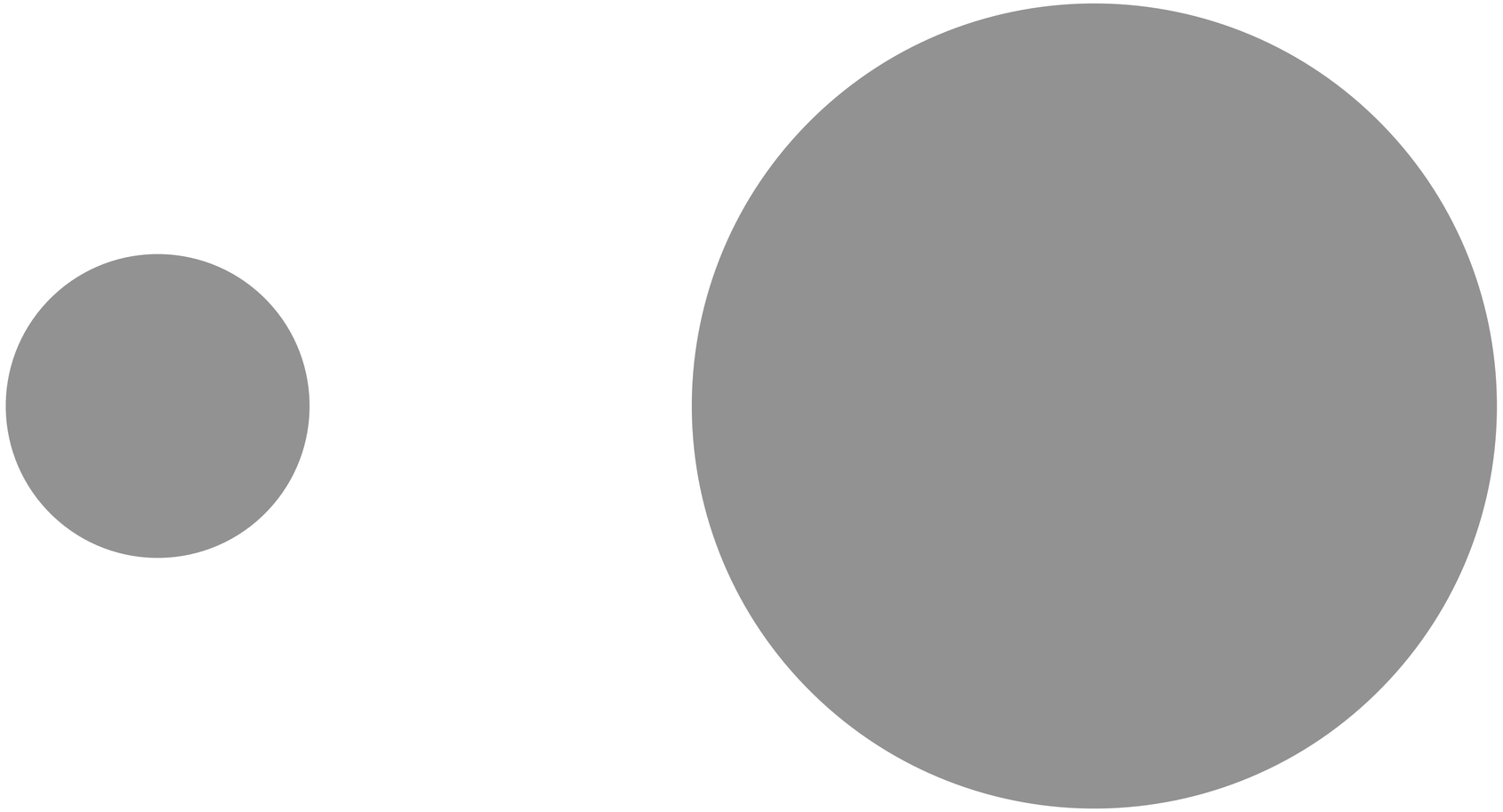
1. Value of visualization
2. Design principles
3. **Graphical perception**

Signal Detection



A Which is brighter? B

Magnitude Estimation



A

B

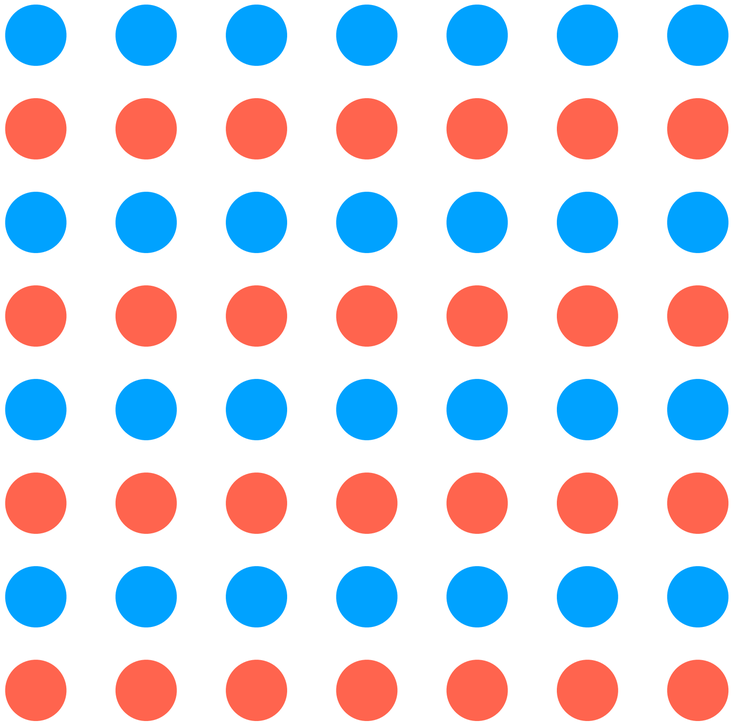
Pre-attentive processing

How Many 3's?

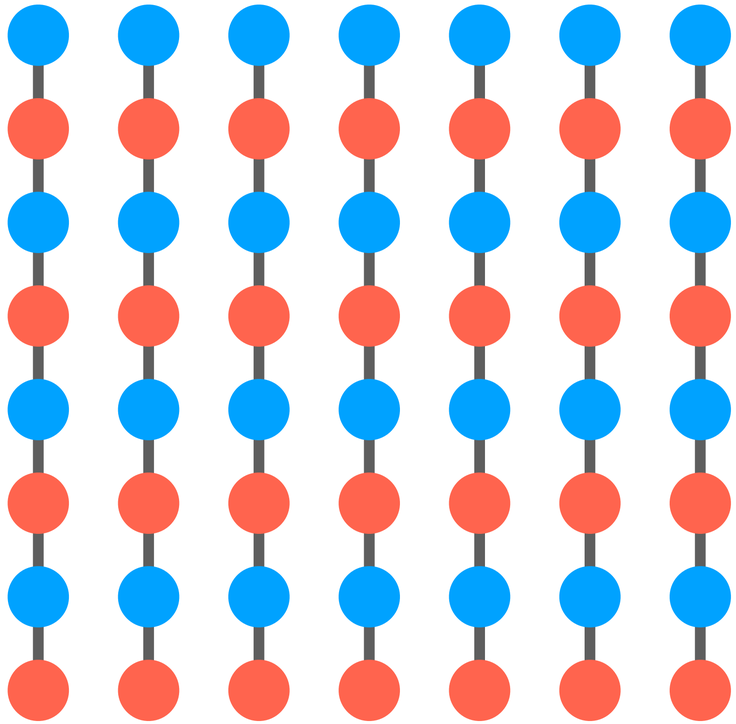
12817687561389765469845069856049828267629809858458224509856458945098450980943585909103020990595959577256467505067890456798809821677654876364908560912949686

12817687561389765469845069856049828267629809858458224509856458945098450980943585909103020990595959577256467505067890456798809821677654876364908560912949686

Gestalt Principles



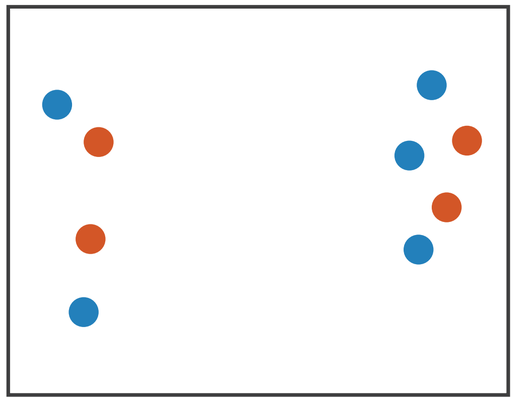
Color **Similarity**



Connection lines

Separability vs. Integrality

Position
+ Hue (Color)

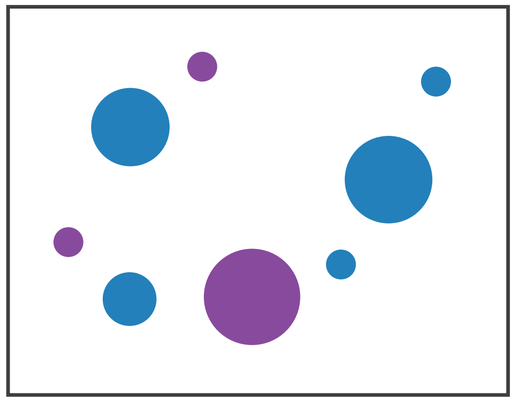


Fully separable

What we perceive:

2 groups each

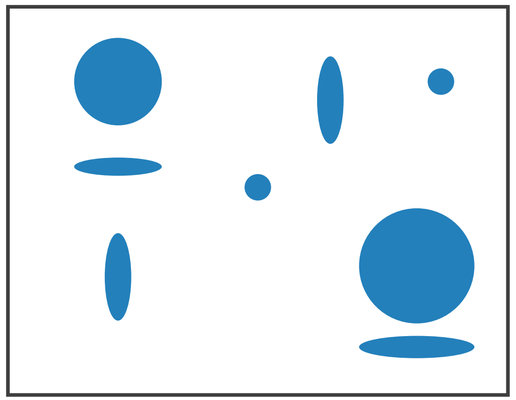
Size
+ Hue (Color)



Some interference

2 groups each

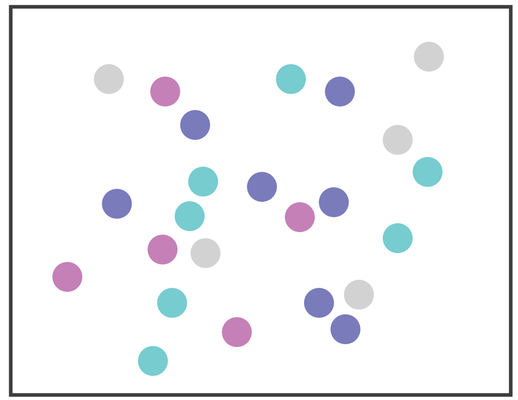
Width
+ Height



Some/significant interference

3 groups total:
integral area

Red
+ Green



Major interference

4 groups total:
integral hue

[Tamara Munzner 14]

Change Blindness

http://www.psych.ubc.ca/~rensink/flicker/download/

Today

Practical

1. Data model and visual encoding
2. Exploratory data analysis
3. Storytelling with data
4. Advanced visualizations

Data Model & Visual Encoding

Nam Wook Kim

Mini-Courses — January @ GSAS
2018

Goal

Learn how data
is mapped to image

The Big Picture

Domain
goals, questions, assumptions

Data
conceptual model
data model

Analysis task
identify, compare
summarize

Processing algorithms
data transformation

Visual encoding
mapping from data to image

Image
marks & channels

[Slides from J. Heer]

Topics

- Data Models
- Image Models
- Visual Encoding
- Formalizing Design

Data Models

Data Models/Conceptual Models

- Conceptual Models are mental constructions of the domain
  Include semantics and support reasoning
- Data Models are formal descriptions of the data
  Derives from a conceptual model.
  Include dimensions & measures.
- Examples (data vs. conceptual)
  Decimal number vs. temperature
  Longitude, latitude vs. geographic location

Taxonomy of Datasets

1D (sets and sequences)

Temporal

2D (maps)

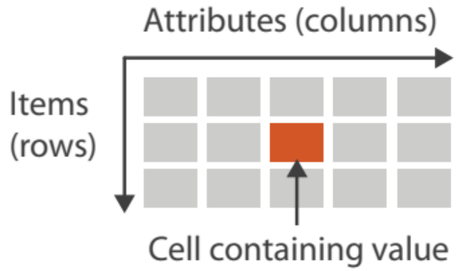
3D (shapes)

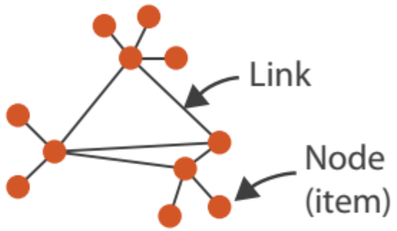
nD (relational)

Trees (hierarchies)

Networks (graphs)

and combinations…





[Shneiderman 96]

Data (Measurement) Scales

N—Nominal

O—Ordinal

Q—Quantitative

Data Scales

N—Nominal (labels or categories)

Fruits: apples, oranges, ...

Data Scales

N—Nominal (labels or categories)
Fruits: apples, oranges, ...

O—Ordinal
Rankings: 1st, 2nd, 3rd…

Data Scales

N—Nominal (labels or categories)

Fruits: apples, oranges, ...

O—Ordinal

Rankings: 1st, 2nd, 3rd…

Q—Quantitative

Interval (location of zero arbitrary)

Dates: Jan, 19, 2006; Location: (LAT 33.98, LONG -118.45)

Only differences (i.e. intervals) are compared

Data Scales

N—Nominal (labels or categories)

Fruits: apples, oranges, ...

O—Ordinal

Rankings: 1st, 2nd, 3rd…

Q—Quantitative

Interval (location of zero arbitrary)

Dates: Jan, 19, 2006; Location: (LAT 33.98, LONG -118.45)

Only differences (i.e. intervals) are compared

Ratio (zero fixed)

Physical measurement: length, amounts, counts

Allow direct comparisons like twice as long

Data Scales

Operations

N—Nominal (labels or categories)

=, ≠

Fruits: apples, oranges, ...

O—Ordinal

Rankings: 1st, 2nd, 3rd…

Q—Quantitative

Interval (location of zero arbitrary)

Dates: Jan, 19, 2006; Location: (LAT 33.98, LONG -118.45)

Only differences (i.e. intervals) are compared

Ratio (zero fixed)

Physical measurement: length, amounts, counts

Allow direct comparisons like twice as long

Data Scales

N—Nominal (labels or categories)

Fruits: apples, oranges, ...

O—Ordinal =, ≠, **<, >**

Rankings: 1st, 2nd, 3rd…

Q—Quantitative

Interval (location of zero arbitrary)

Dates: Jan, 19, 2006; Location: (LAT 33.98, LONG -118.45)

Only differences (i.e. intervals) are compared

Ratio (zero fixed)

Physical measurement: length, amounts, counts

Allow direct comparisons like twice as long

Data Scales

N—Nominal (labels or categories)

Fruits: apples, oranges, ...

O—Ordinal

Rankings: 1st, 2nd, 3rd…

Q—Quantitative

=, ≠, <, >, −

Interval (location of zero arbitrary)

Can measure distances or spans

Dates: Jan, 19, 2006; Location: (LAT 33.98, LONG -118.45)

Only differences (i.e. intervals) are compared

Ratio (zero fixed)

Physical measurement: length, amounts, counts

Allow direct comparisons like twice as long

Data Scales

N—Nominal (labels or categories)

Fruits: apples, oranges, ...

O—Ordinal

Rankings: 1st, 2nd, 3rd…

Q—Quantitative

Interval (location of zero arbitrary)

Dates: Jan, 19, 2006; Location: (LAT 33.98, LONG -118.45)

Only differences (i.e. intervals) are compared

Ratio (zero fixed)

Physical measurement: length, amounts, counts

Allow direct comparisons like twice as long

=, ≠, <, >, –, **/** (%)

Can measure ratios or proportions

Example

Conceptual Model
- Temperature (°C)

Data Model
- 32.5, 54.0, -17.3, ...
- Decimal numbers

Data Scales
- Temperature Value (Q)
- Burned vs. Not-Burned (N) — Derived
- Hot, Warm, Cold (O) — Derived

Dimensions & Measures

Dimensions (~ independent variables)

- Often discrete variables describing data (N, O)
- Categories, dates, binned quantities

Measures (~ dependent variables)

- Continuous values that can be aggregated (Q)
- Numbers to be analyzed
- Aggregate as sum, count, average, std. dev…

Not a strict distinction. The same variable may be treated either way depending on the task (e.g. Year: 2001, 2002 …).

Example: U.S. Census Data

U.S. Census Data

Year: 1850 – 2000 (every decade)

Age: 0 – 90+

Marital Status: Single, Married, Divorced, …

Sex: Male, Female

People Count: # of people in group

2,348 data points

	A	B	C	D	E
1	year	age	marst	sex	people
2	1850	0	0	1	1483789
3	1850	0	0	2	1450376
4	1850	5	0	1	1411067
5	1850	5	0	2	1359668
6	1850	10	0	1	1260099
7	1850	10	0	2	1216114
8	1850	15	0	1	1077133
9	1850	15	0	2	1110619
10	1850	20	0	1	1017281
11	1850	20	0	2	1003841
12	1850	25	0	1	862547
13	1850	25	0	2	799482
14	1850	30	0	1	730638
15	1850	30	0	2	639636
16	1850	35	0	1	588487
17	1850	35	0	2	505012
18	1850	40	0	1	475911
19	1850	40	0	2	428185
20	1850	45	0	1	384211
21	1850	45	0	2	341254
22	1850	50	0	1	321343
23	1850	50	0	2	286580
24	1850	55	0	1	194080
25	1850	55	0	2	187208
26	1850	60	0	1	174976
27	1850	60	0	2	162236
28	1850	65	0	1	106827
29	1850	65	0	2	105534

U.S. Census Data

Year	Q-Interval (O)
Age	Q-Ratio (O)
Marital Status	N
Sex	N
People Count	Q-Ratio

	A	B	C	D	E
1	year	age	marst	sex	people
2	1850	0	0	1	1483789
3	1850	0	0	2	1450376
4	1850	5	0	1	1411067
5	1850	5	0	2	1359668
6	1850	10	0	1	1260099
7	1850	10	0	2	1216114
8	1850	15	0	1	1077133
9	1850	15	0	2	1110619
10	1850	20	0	1	1017281
11	1850	20	0	2	1003841
12	1850	25	0	1	862547
13	1850	25	0	2	799482
14	1850	30	0	1	730638
15	1850	30	0	2	639636
16	1850	35	0	1	588487
17	1850	35	0	2	505012
18	1850	40	0	1	475911
19	1850	40	0	2	428185
20	1850	45	0	1	384211
21	1850	45	0	2	341254
22	1850	50	0	1	321343
23	1850	50	0	2	286580
24	1850	55	0	1	194080
25	1850	55	0	2	187208
26	1850	60	0	1	174976
27	1850	60	0	2	162236
28	1850	65	0	1	106827
29	1850	65	0	2	105534

U.S. Census Data

Year	Depends!
Age	Depends!
Marital Status	Dimension
Sex	Dimension
People Count	Measure

	A	B	C	D	E
1	year	age	marst	sex	people
2	1850	0	0	1	1483789
3	1850	0	0	2	1450376
4	1850	5	0	1	1411067
5	1850	5	0	2	1359668
6	1850	10	0	1	1260099
7	1850	10	0	2	1216114
8	1850	15	0	1	1077133
9	1850	15	0	2	1110619
10	1850	20	0	1	1017281
11	1850	20	0	2	1003841
12	1850	25	0	1	862547
13	1850	25	0	2	799482
14	1850	30	0	1	730638
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16	1850	35	0	1	588487
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18	1850	40	0	1	475911
19	1850	40	0	2	428185
20	1850	45	0	1	384211
21	1850	45	0	2	341254
22	1850	50	0	1	321343
23	1850	50	0	2	286580
24	1850	55	0	1	194080
25	1850	55	0	2	187208
26	1850	60	0	1	174976
27	1850	60	0	2	162236
28	1850	65	0	1	106827
29	1850	65	0	2	105534

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

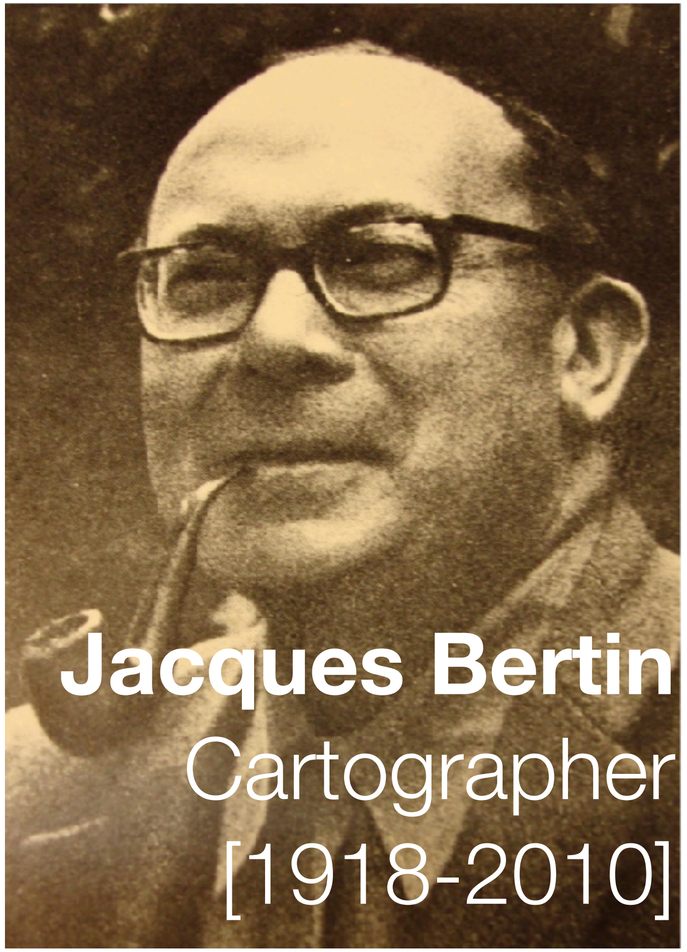


Image Models

Marks

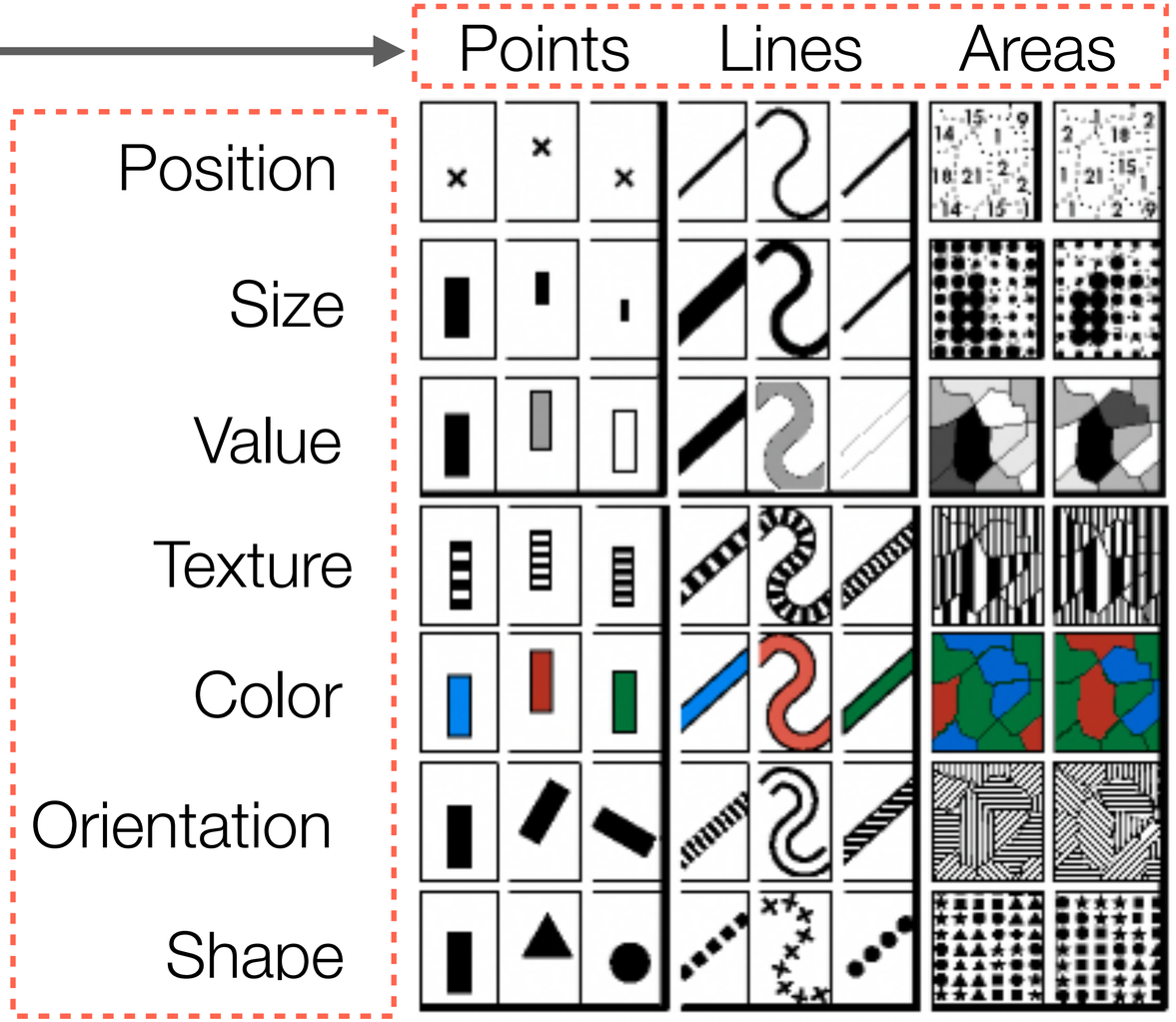
Basic graphical elements in an image

Represent information

Channels (visual variables)

Control the appearance of marks

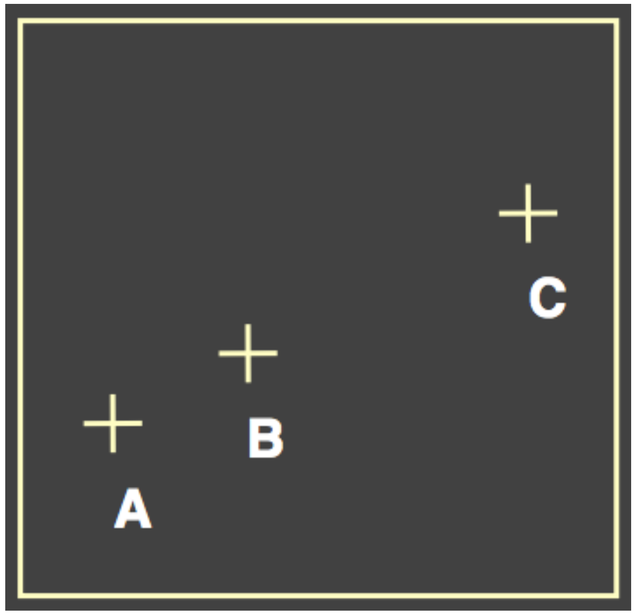
Encode information



Coding Information in Position

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

∴ Encode quantitative variables (Q)



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

Coding 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)

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

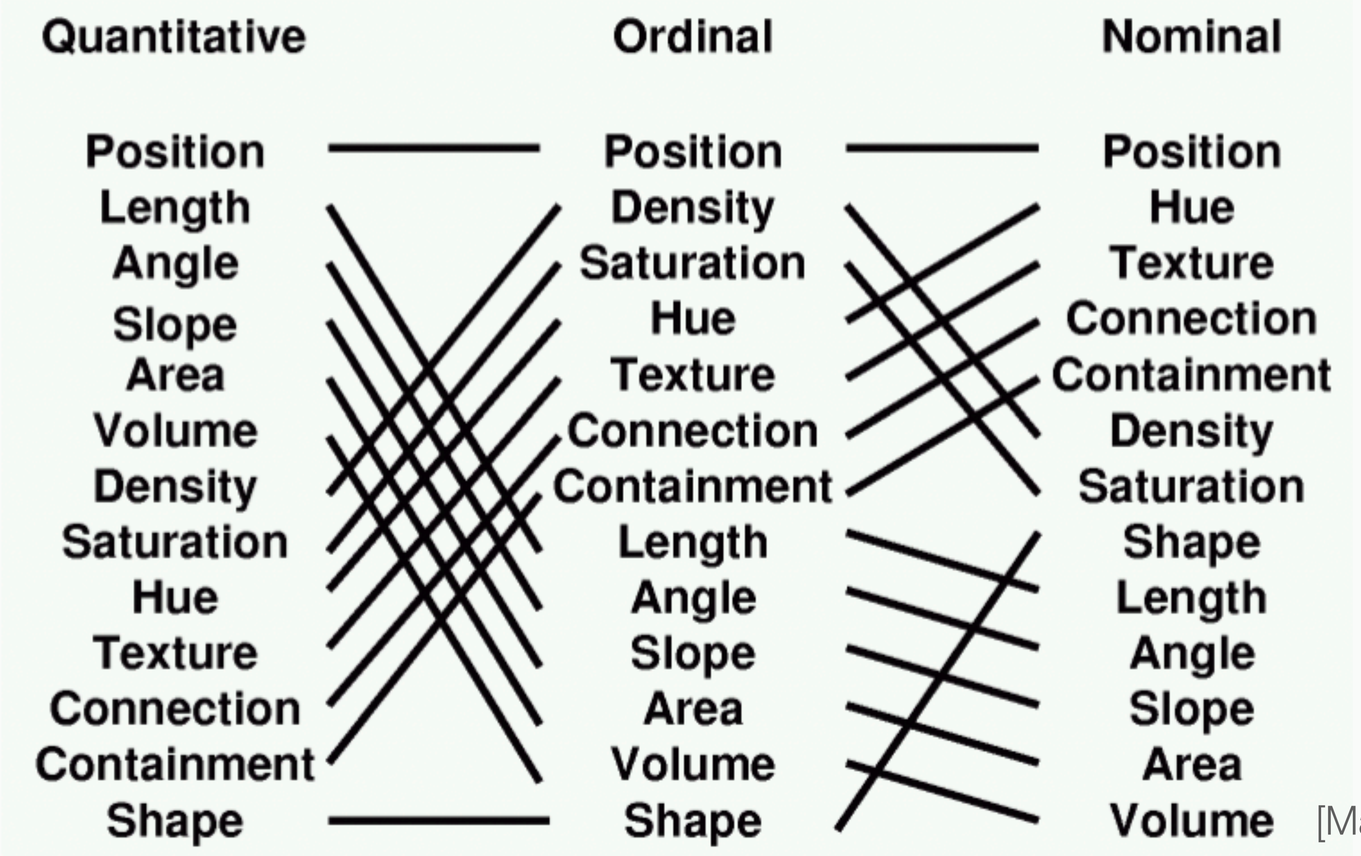
Ordinal

Quantitative

Note: **Q** ⊂ **O** ⊂ **N**

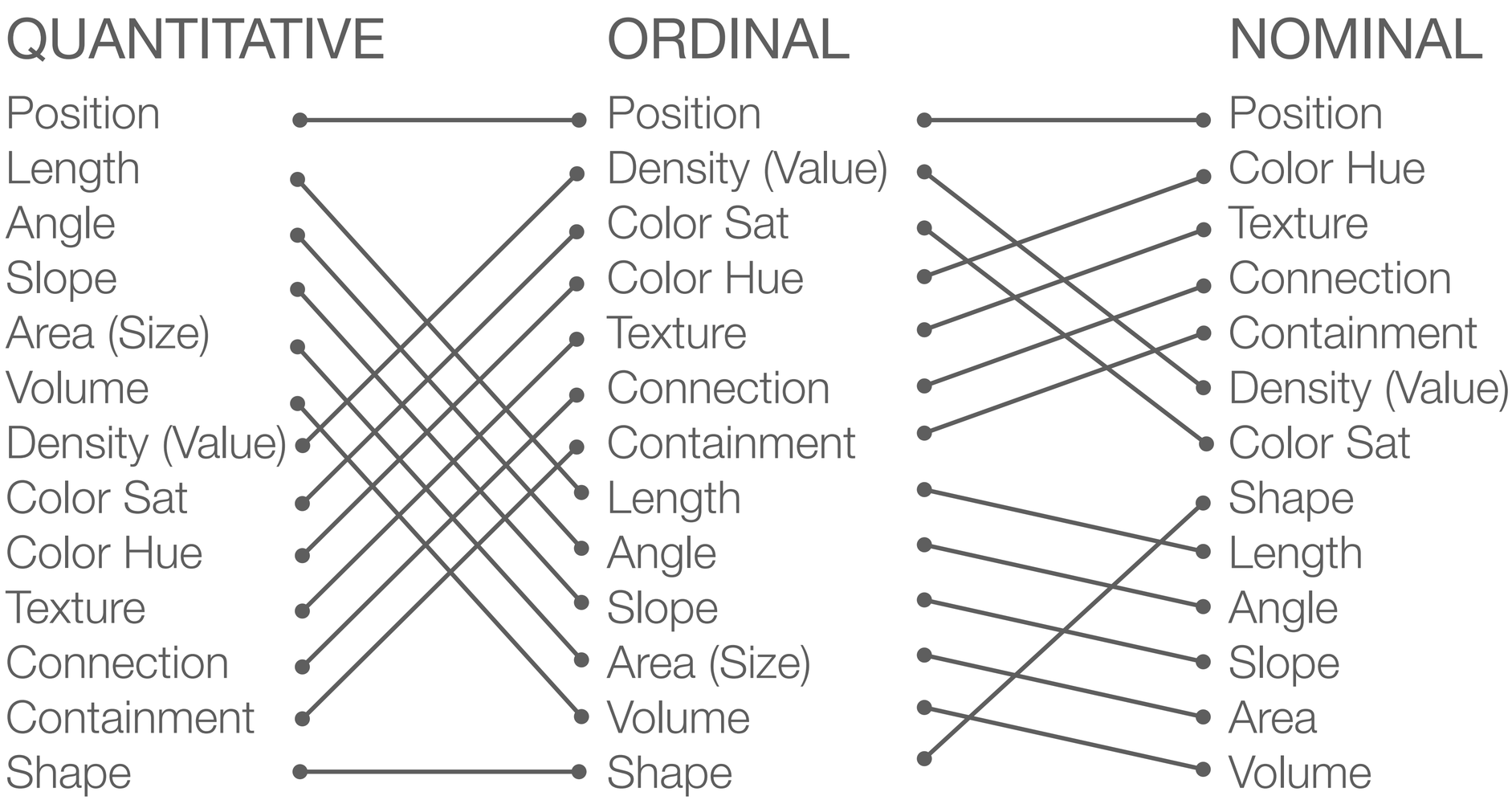
Mackinlay's Ranking

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



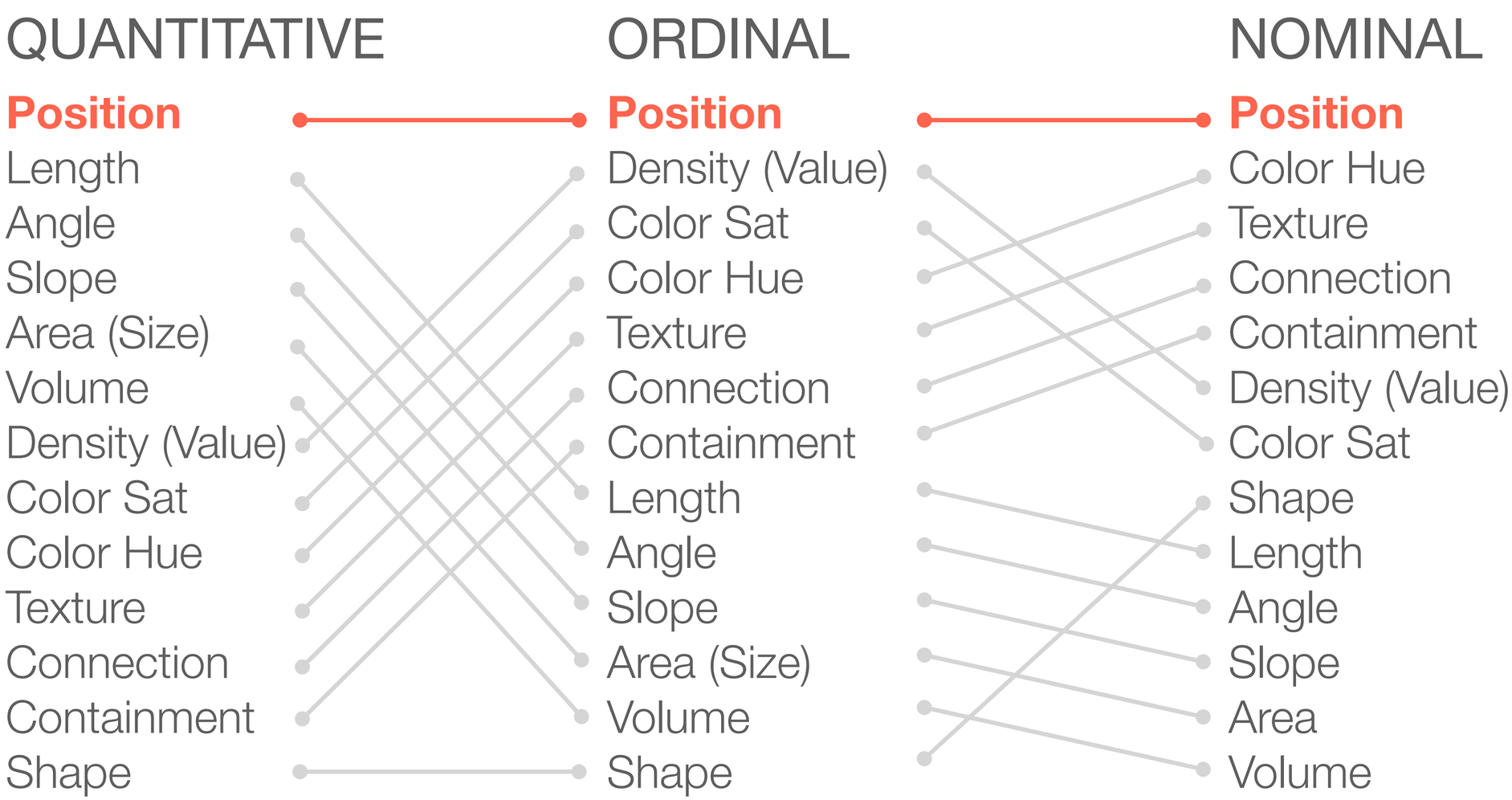
[Mackinlay 86]

Effectiveness Rankings



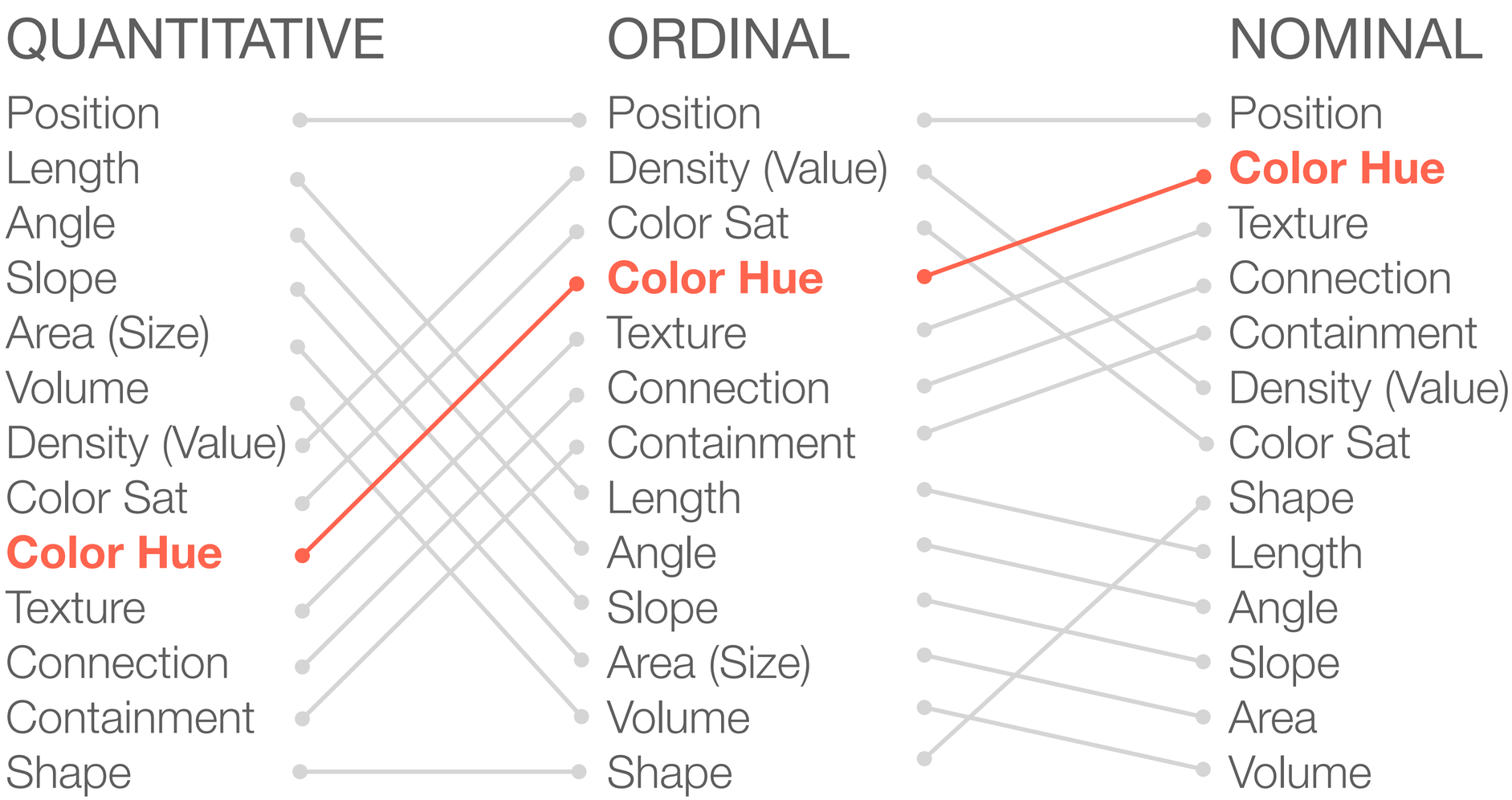
[Mackinlay 86]

Effectiveness Rankings



[Mackinlay 86]

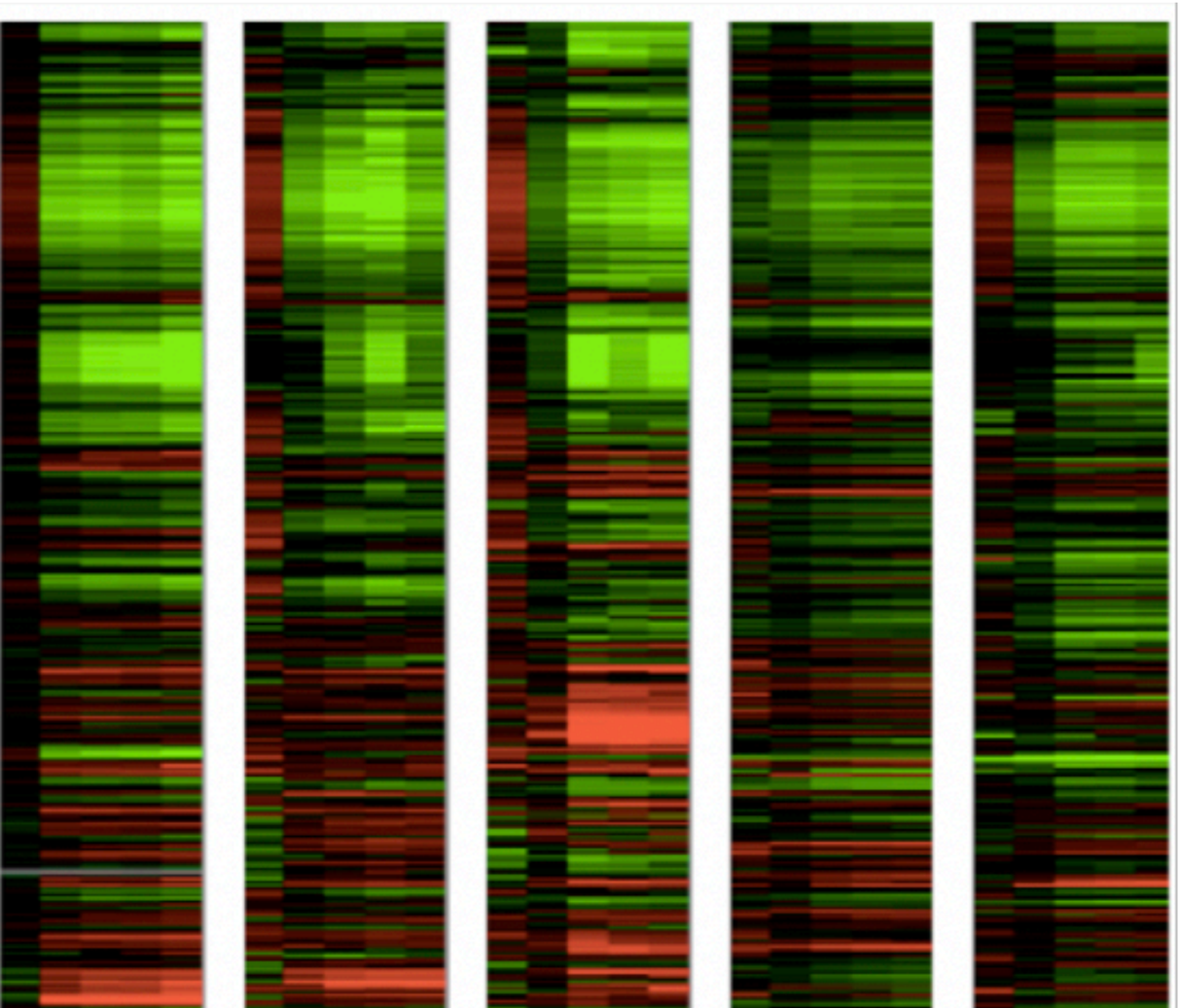
Effectiveness Rankings



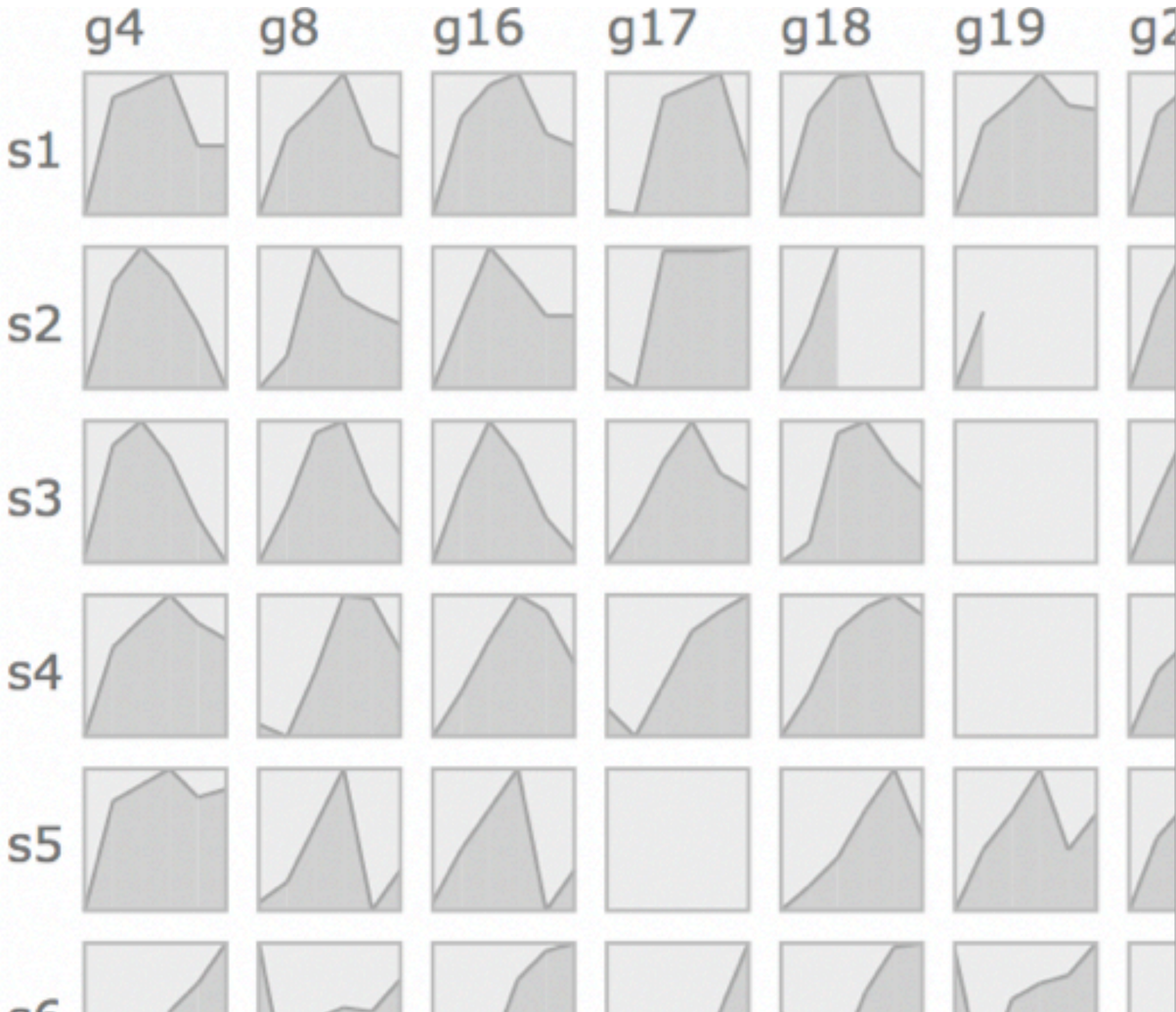
[Mackinlay 86]

Gene Expression Time-Series [Meyer et al '11]

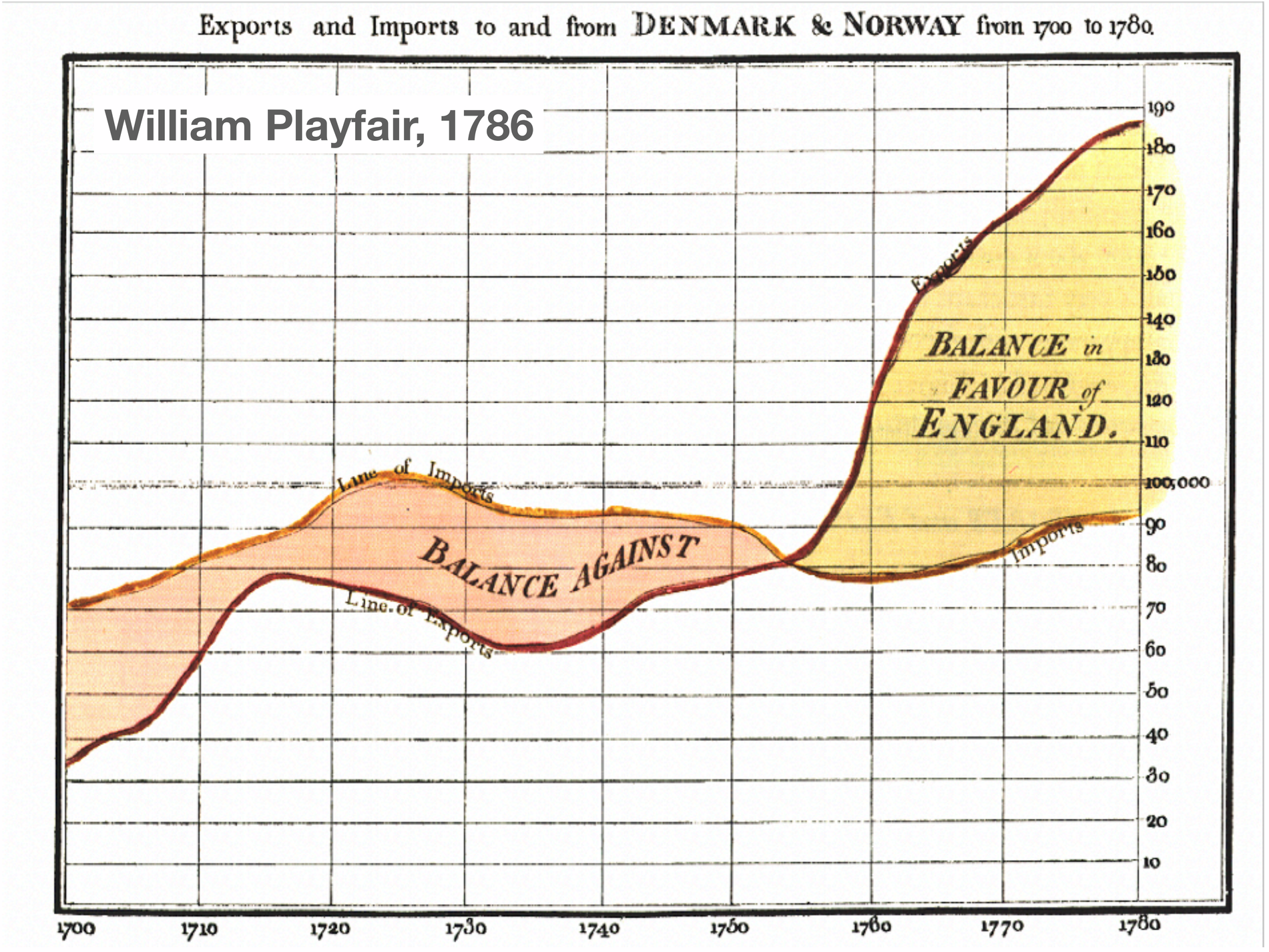
Color Encoding

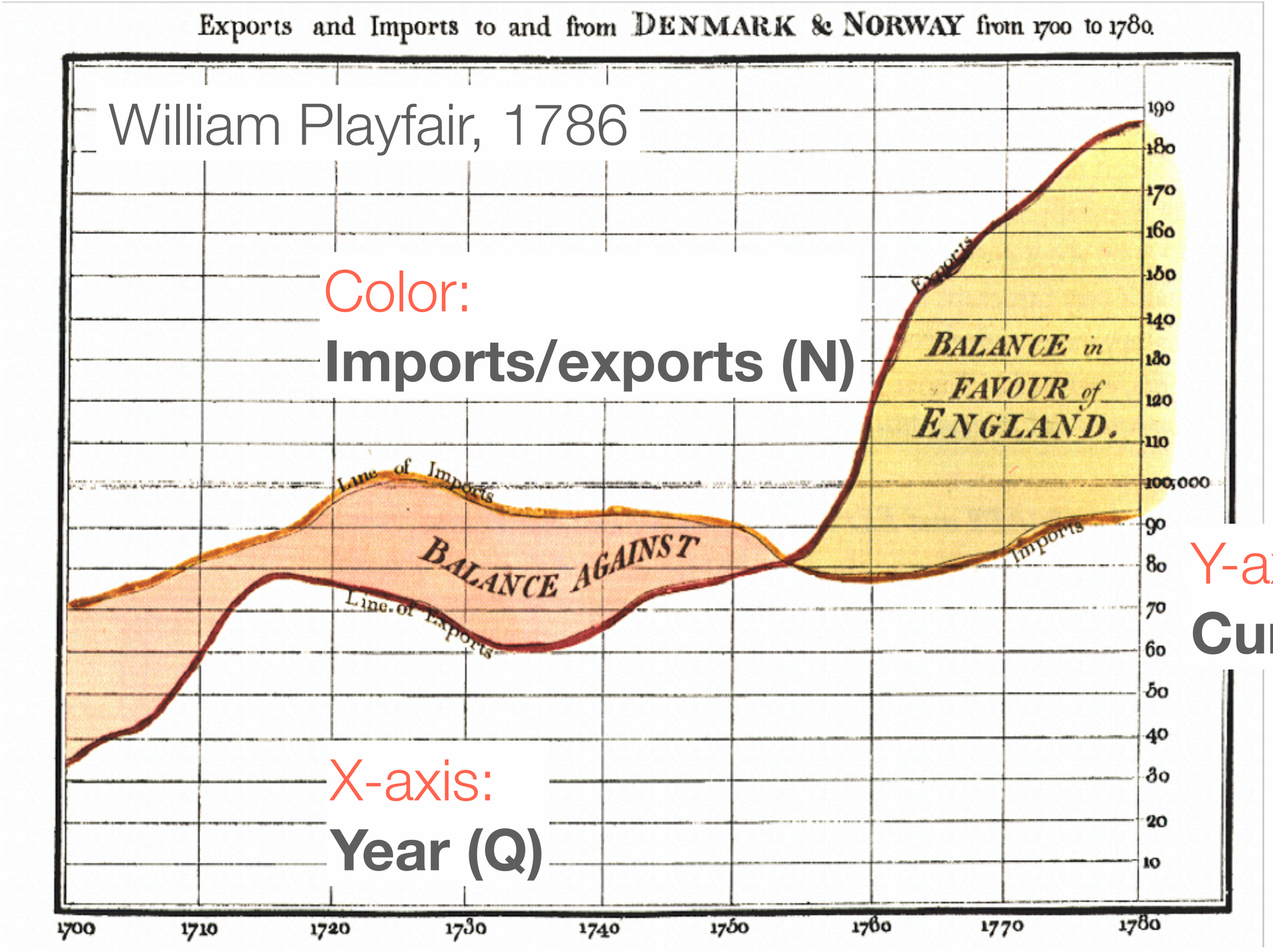


Position Encoding

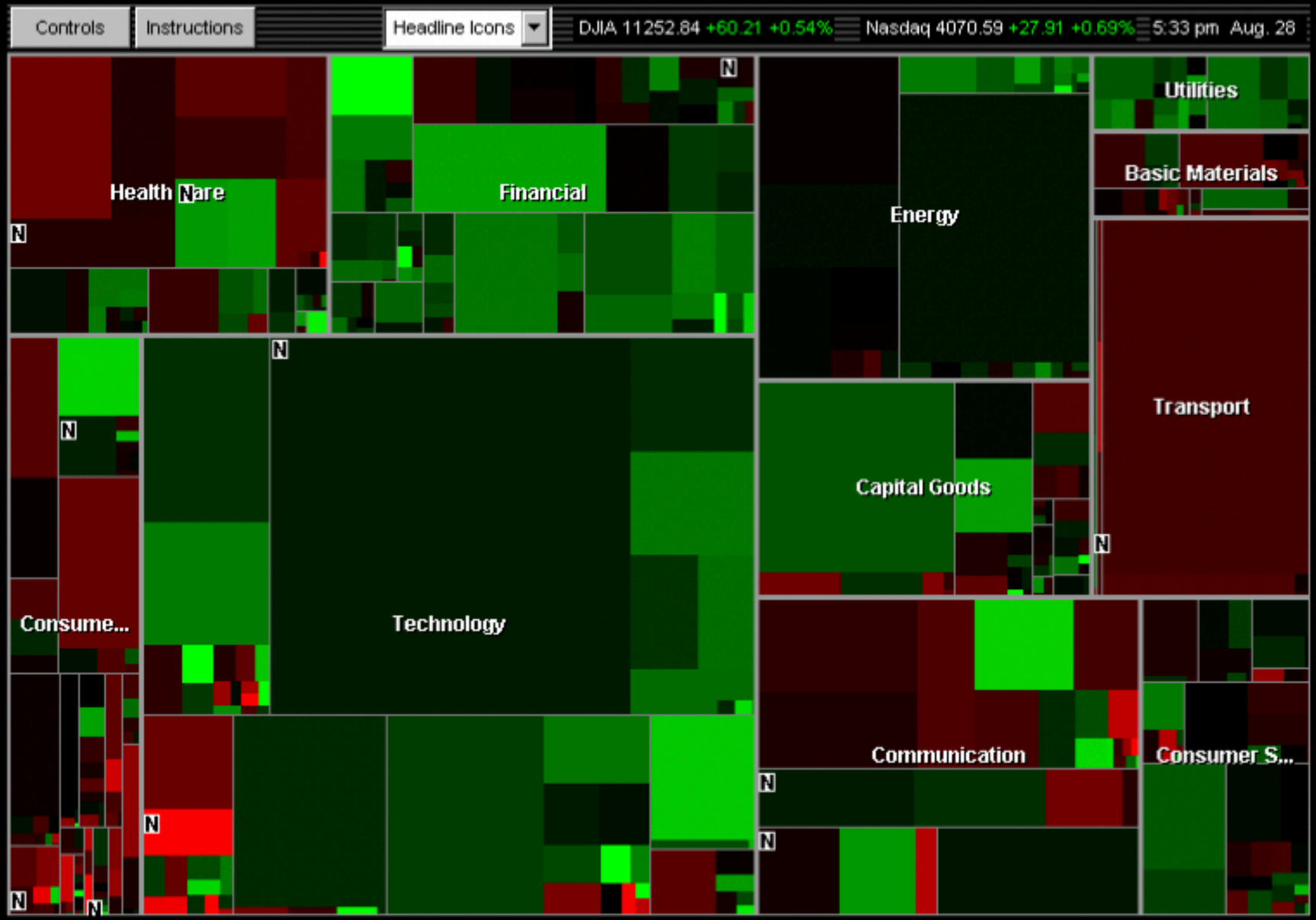


Example: Deconstructions


Exports and Imports to and from DENMARK & NORWAY from 1700 to 1780.
William Playfair, 1786
BALANCE in FAVOUR of ENGLAND.
BALANCE AGAINST
Line of Imports
Line of Exports
Exports
Imports
190
180
170
160
150
140
130
120
110
100,000
90
80
70
60
50
40
30
20
10
1700
1710
1720
1730
1740
1750
1760
1770
1780


Exports and Imports to and from DENMARK & NORWAY from 1700 to 1780.
William Playfair, 1786
Color:
Imports/exports (N)
Y-axis:
Currency (Q)
X-axis:
Year (Q)
BALANCE in FAVOUR of ENGLAND.
BALANCE AGAINST
Line of Imports
Line of Exports
Exports
Imports
190
180
170
160
150
140
130
120
110
100,000
90
80
70
60
50
40
30
20
10
1700
1710
1720
1730
1740
1750
1760
1770
1780

Wattenberg's Map of the Market

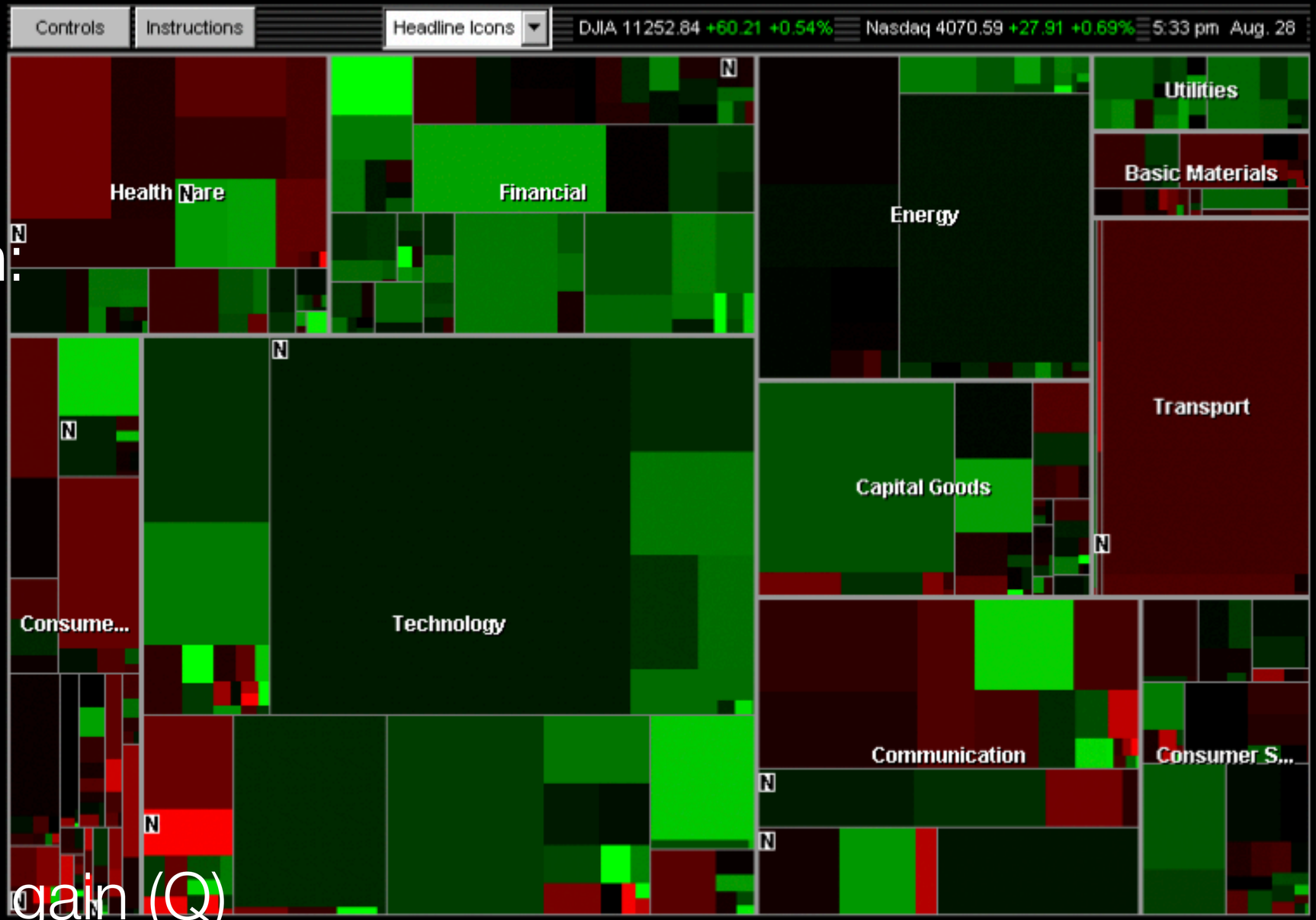


Rectangle Area:
market cap (Q)

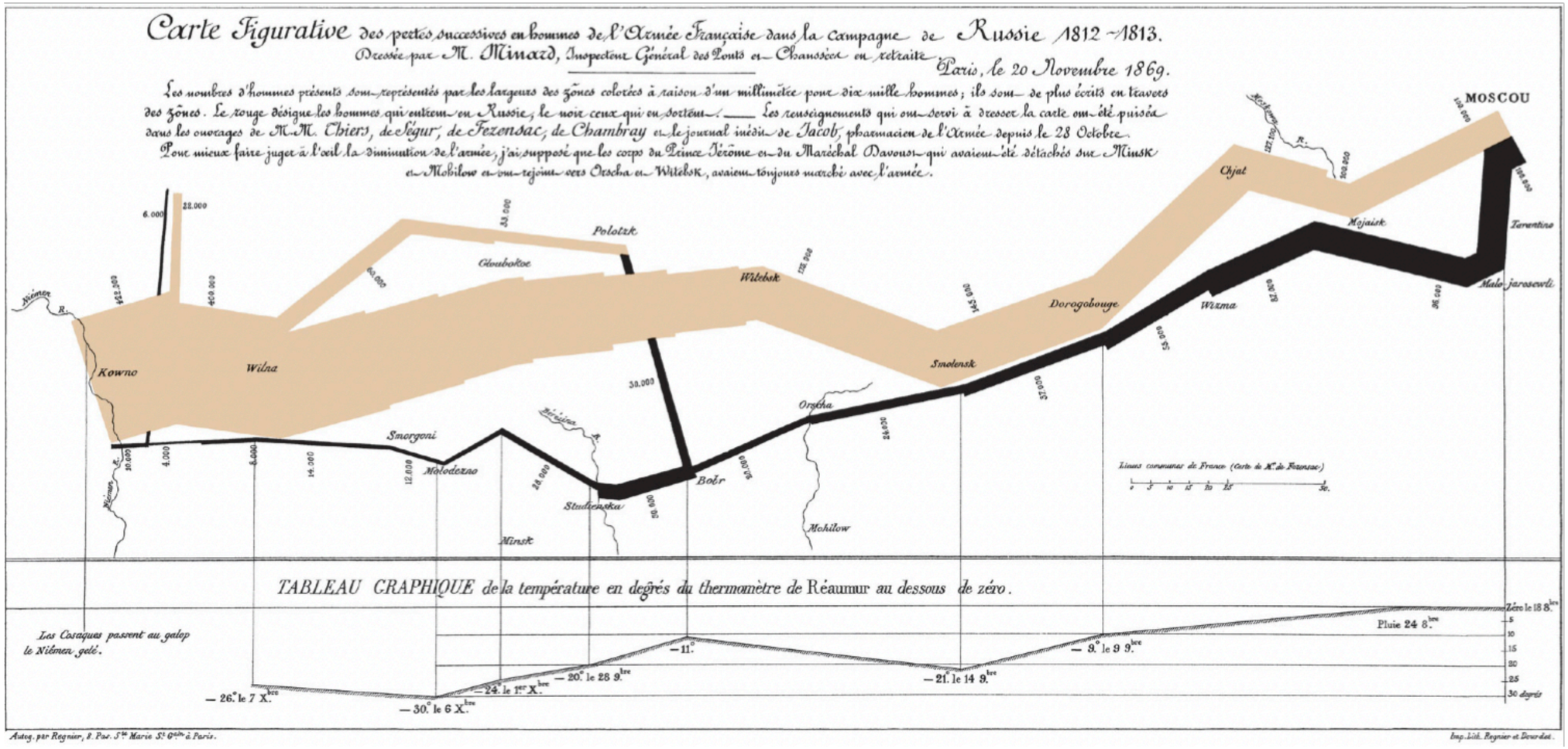
Rectangle Position:
market sector (N),
market cap (Q)

Color Hue:
loss vs. gain (N)

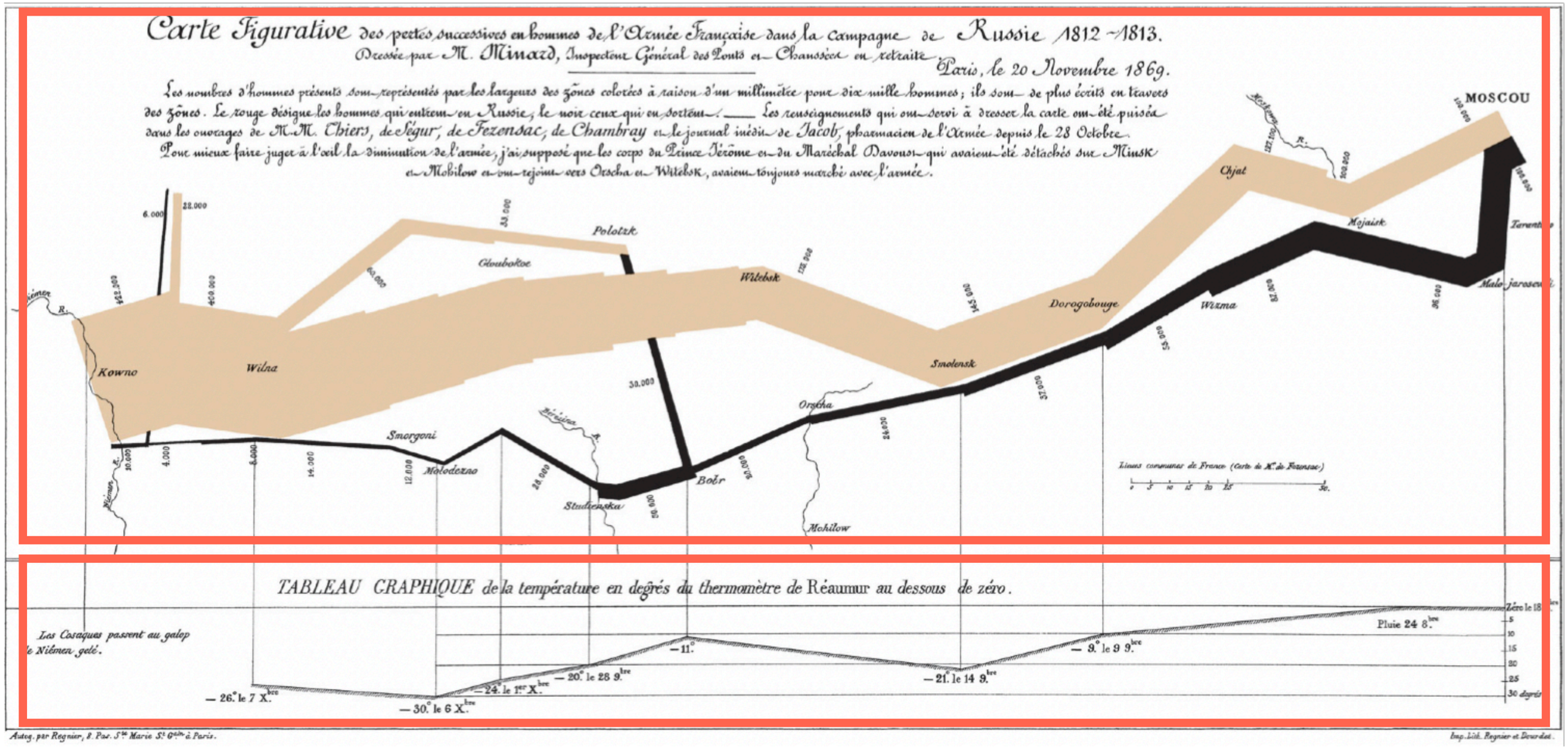
Color Value:
magnitude of loss or gain (Q)



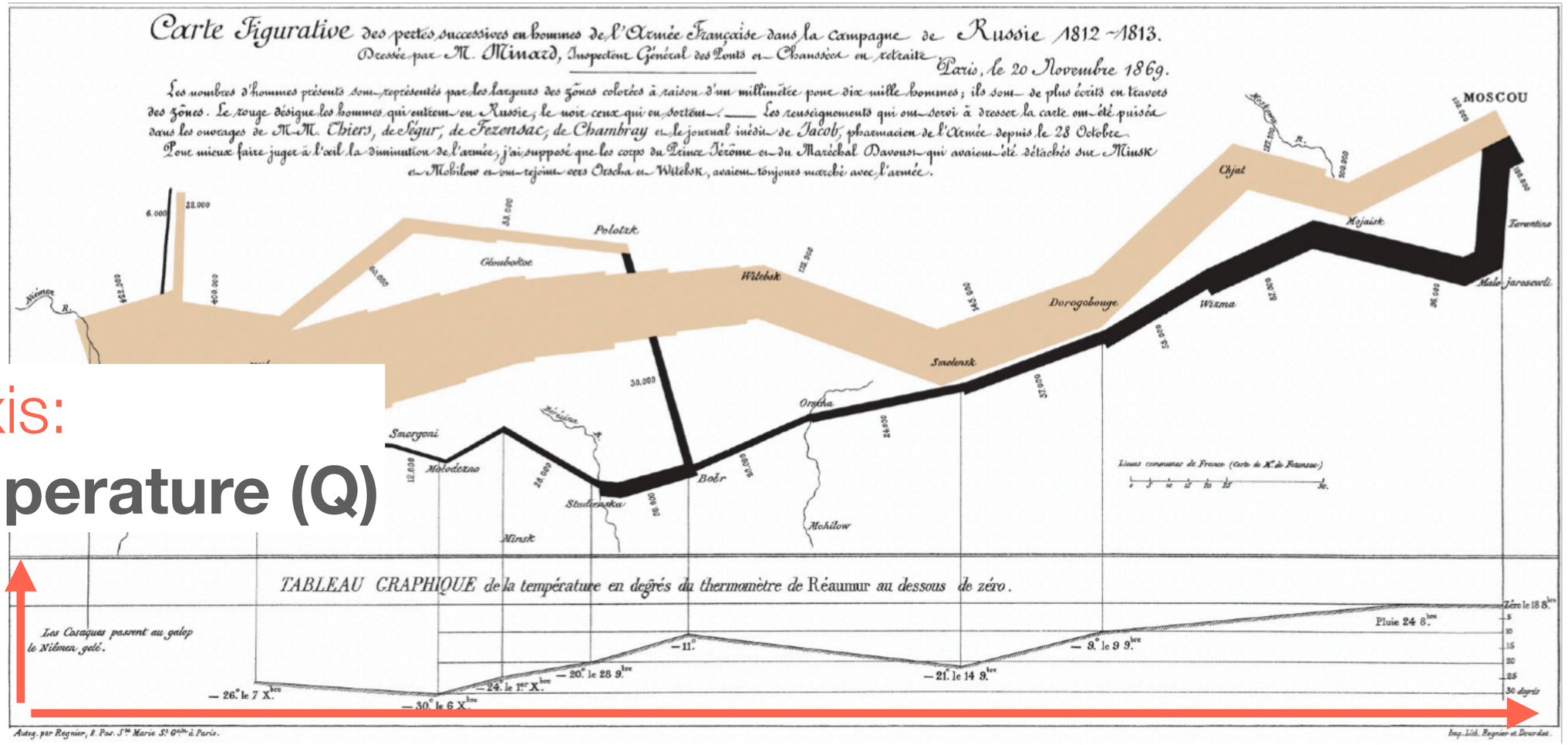
Minard 1869: Napoleon's March



Minard 1869: Napoleon's March



Minard 1869: Napoleon's March



Y-axis:

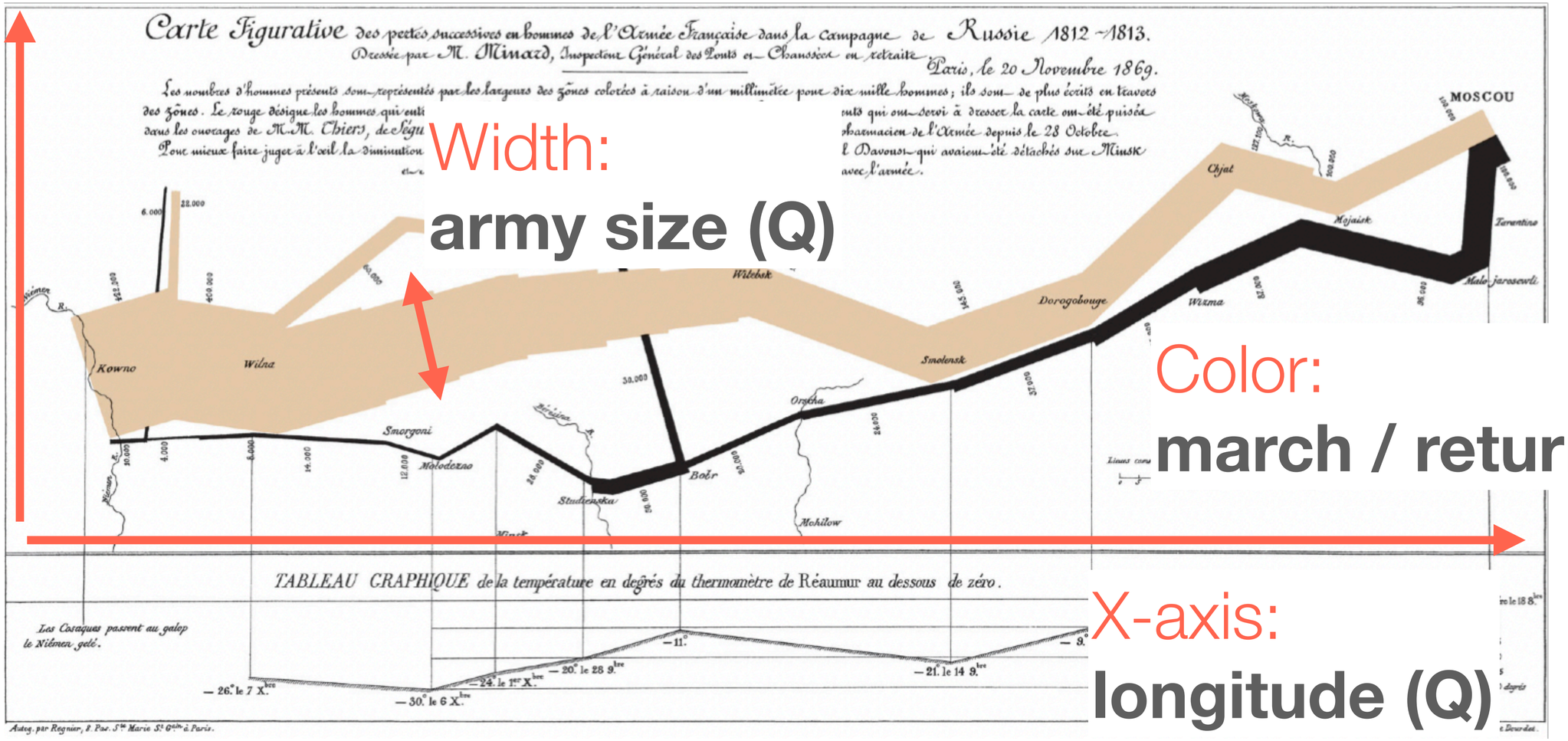
temperature (Q)

X-axis:

longitude (Q) / time (O)

Minard 1869: Napoleon's March

Y-axis:
latitude (Q)

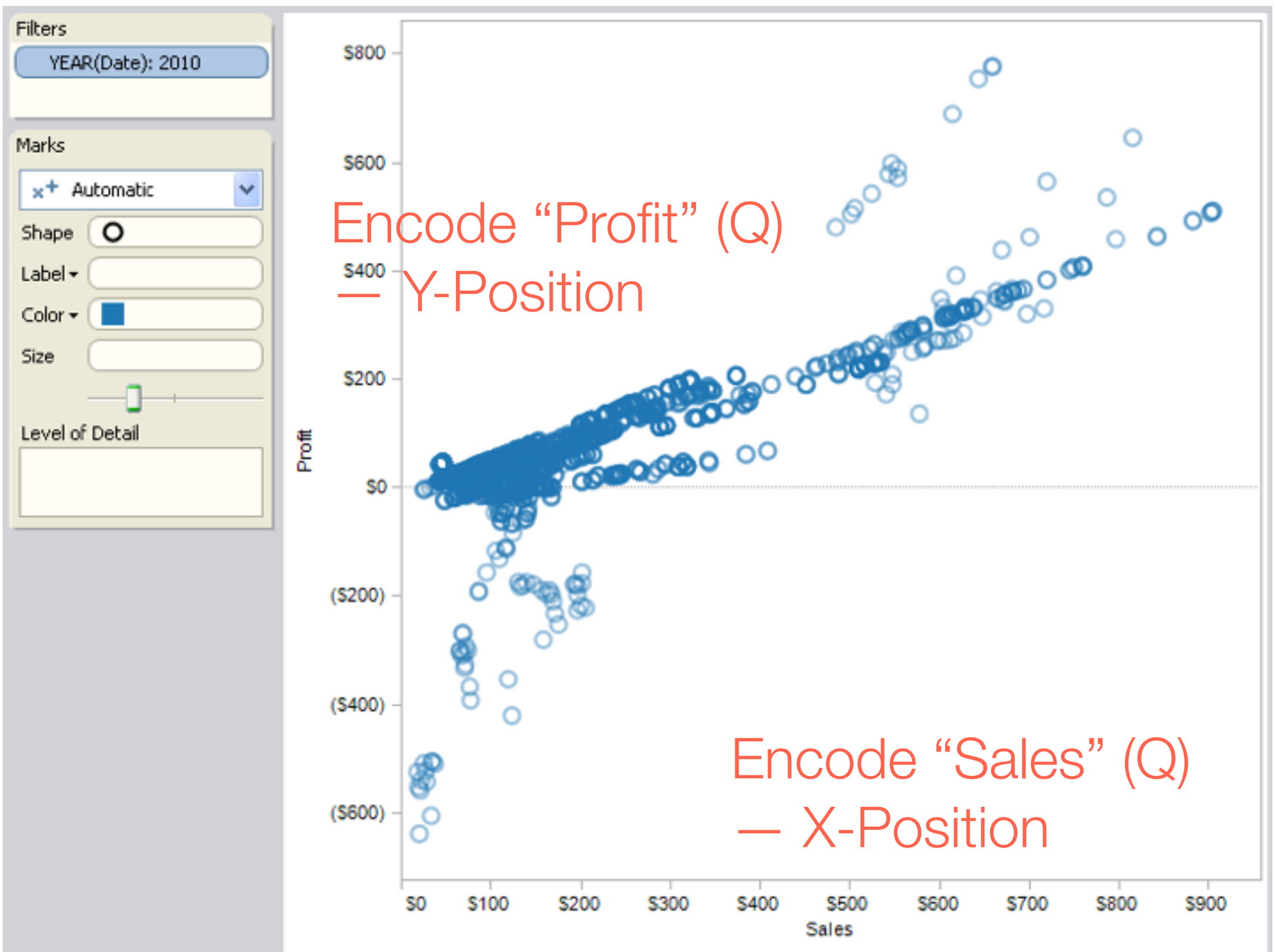


Example: Encoding Data

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

Filters

YEAR(Date): 2010

Marks

Automatic

Shape

Label

Color Product Type

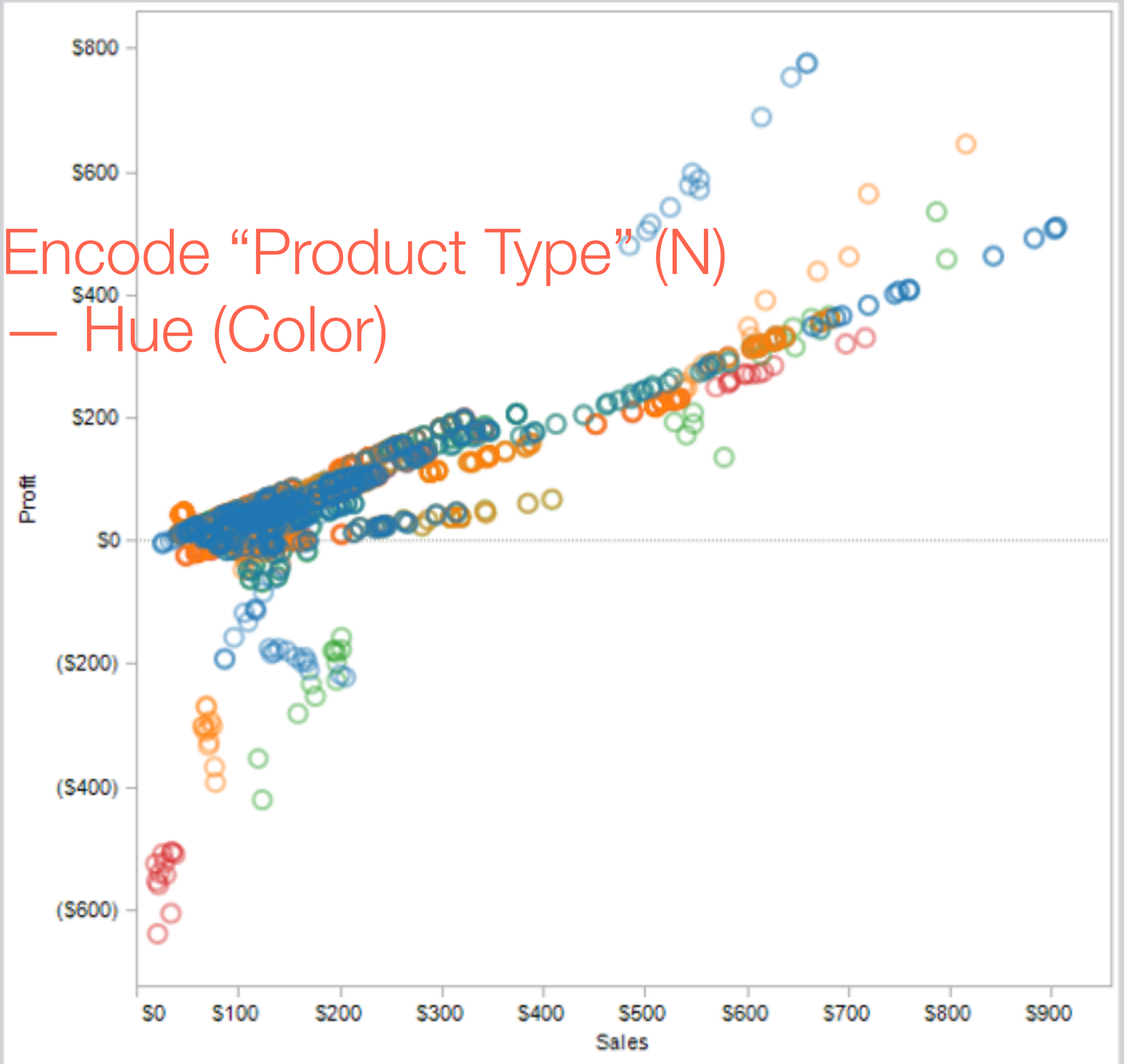
Size

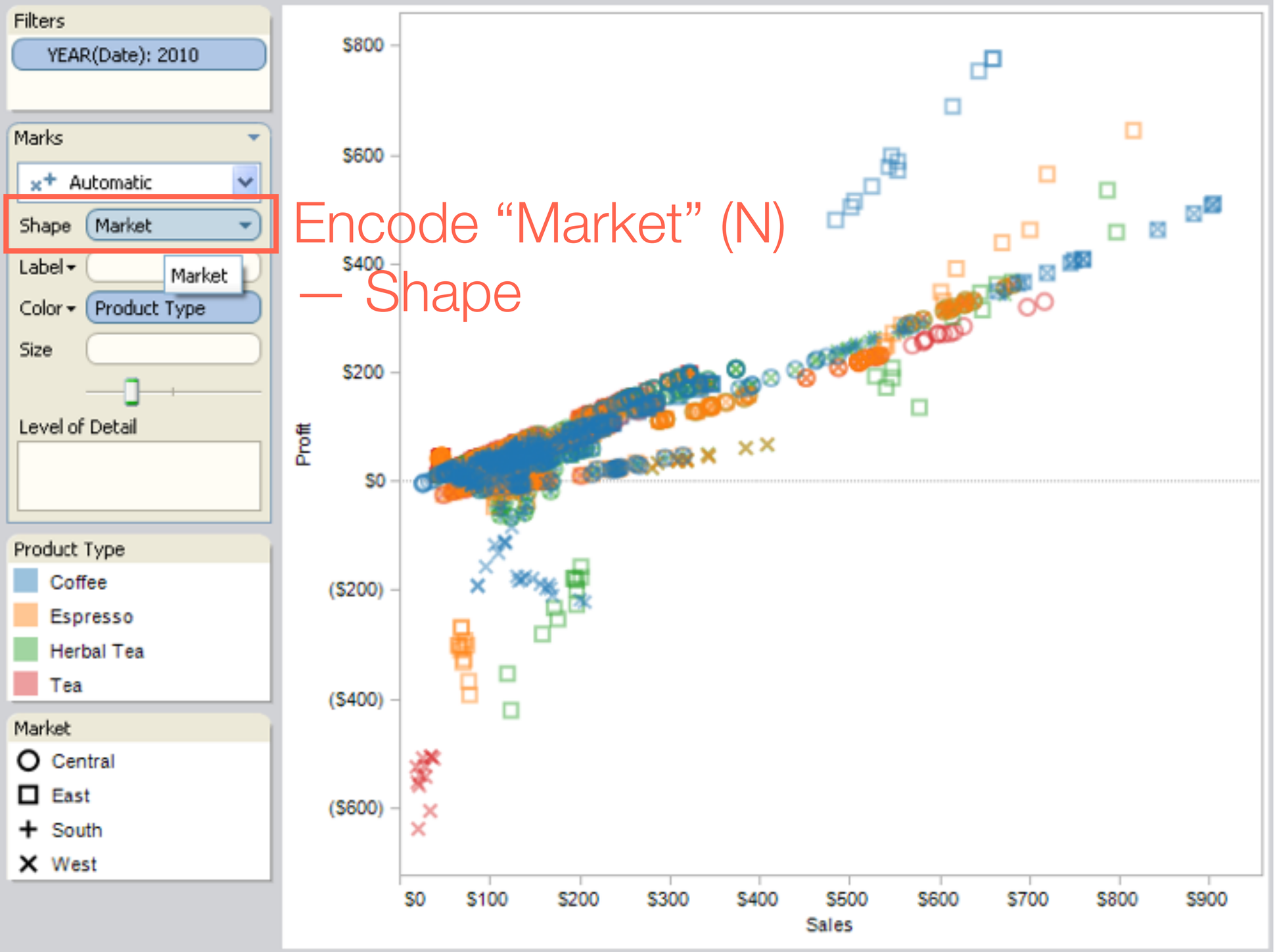
Level of Detail

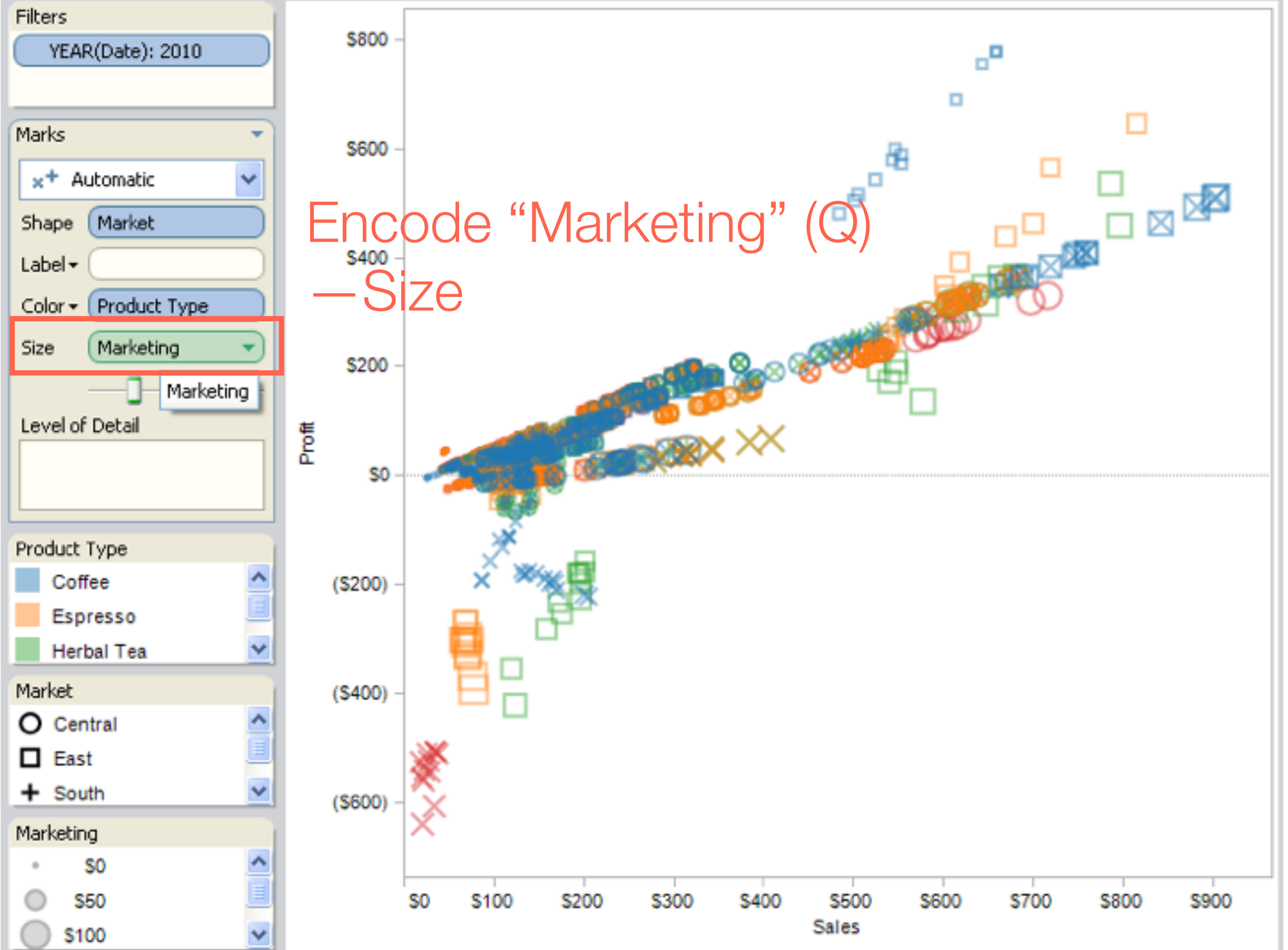
Product Type

- Coffee
- Espresso
- Herbal Tea
- Tea

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



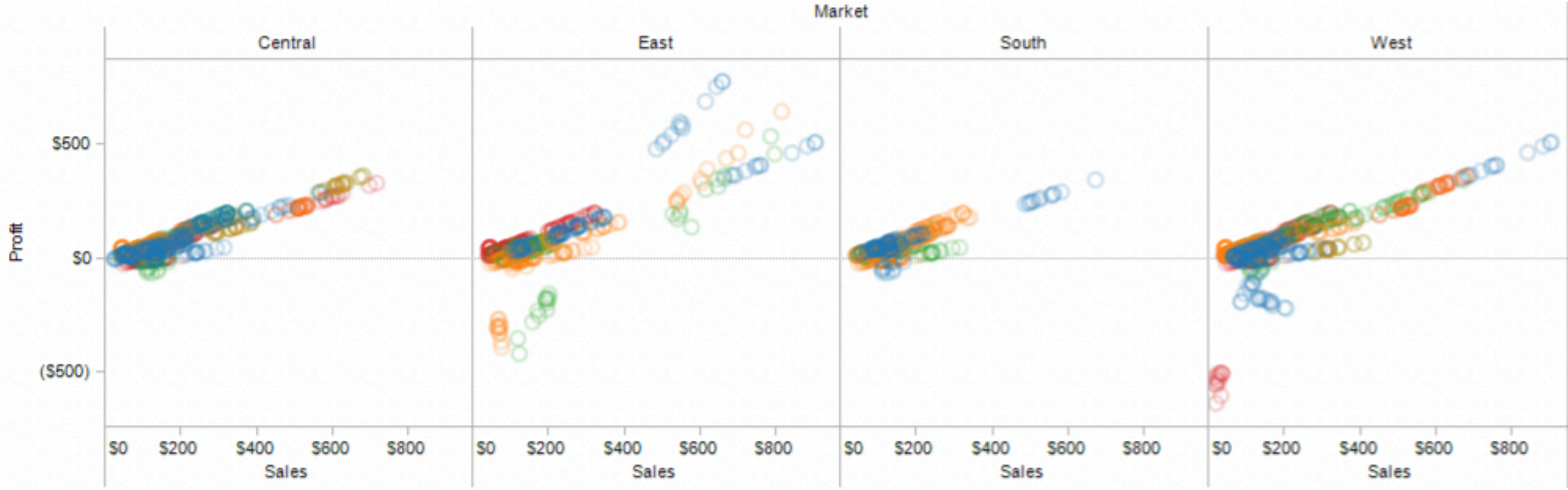

Filters
YEAR(Date): 2010
Marks
Automatic
Shape
Market
Label
Color
Product Type
Size
Level of Detail
Market
Encode “Market” (N)
— Shape
Product Type
Coffee
Espresso
Herbal Tea
Tea
Market
Central
East
South
West
$800
$600
$400
$200
$0
($200)
($400)
($600)
Profit
$0
$100
$200
$300
$400
$500
$600
$700
$800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


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
Are you satisfied with this chart?

Avoid over-encoding

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



Formalizing Design

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 $(n+1)^k$

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 $(n+1)^k$

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

Expressiveness

A set of facts is expressible in a visual language if the sentences (i.e. the visualizations) in the language express all the facts in the set of data, and only the facts in the data.

Effectiveness

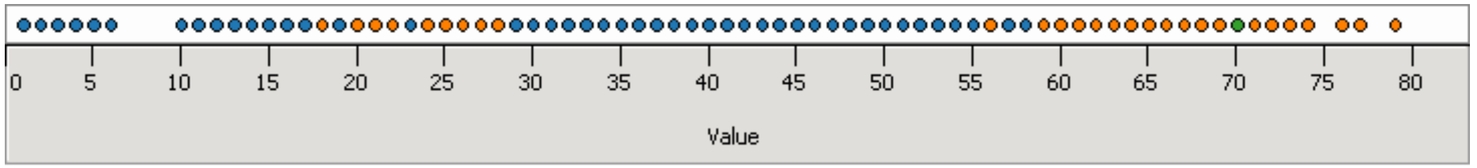
[Mackinlay 86]

Design Criteria Translated

Tell the truth and nothing but the truth
(don’t lie, and don’t lie by omission)

Can not express the facts

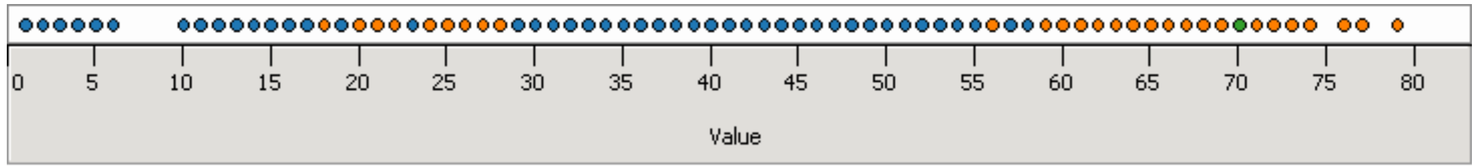
A multivariate relation may be inexpressive in a single horizontal dot plot because multiple records are mapped to the same position.



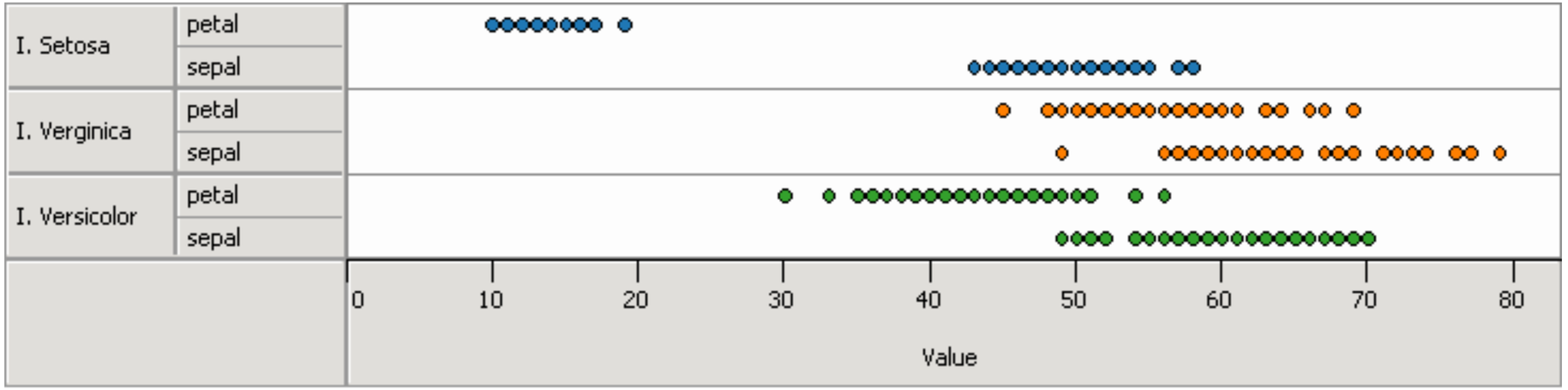
Single horizontal dot plot

Can not express the facts

A multivariate relation may be inexpressive in a single horizontal dot plot because multiple records are mapped to the same position.



Single horizontal dot plot



Categories in different positions

Expresses facts not in the data

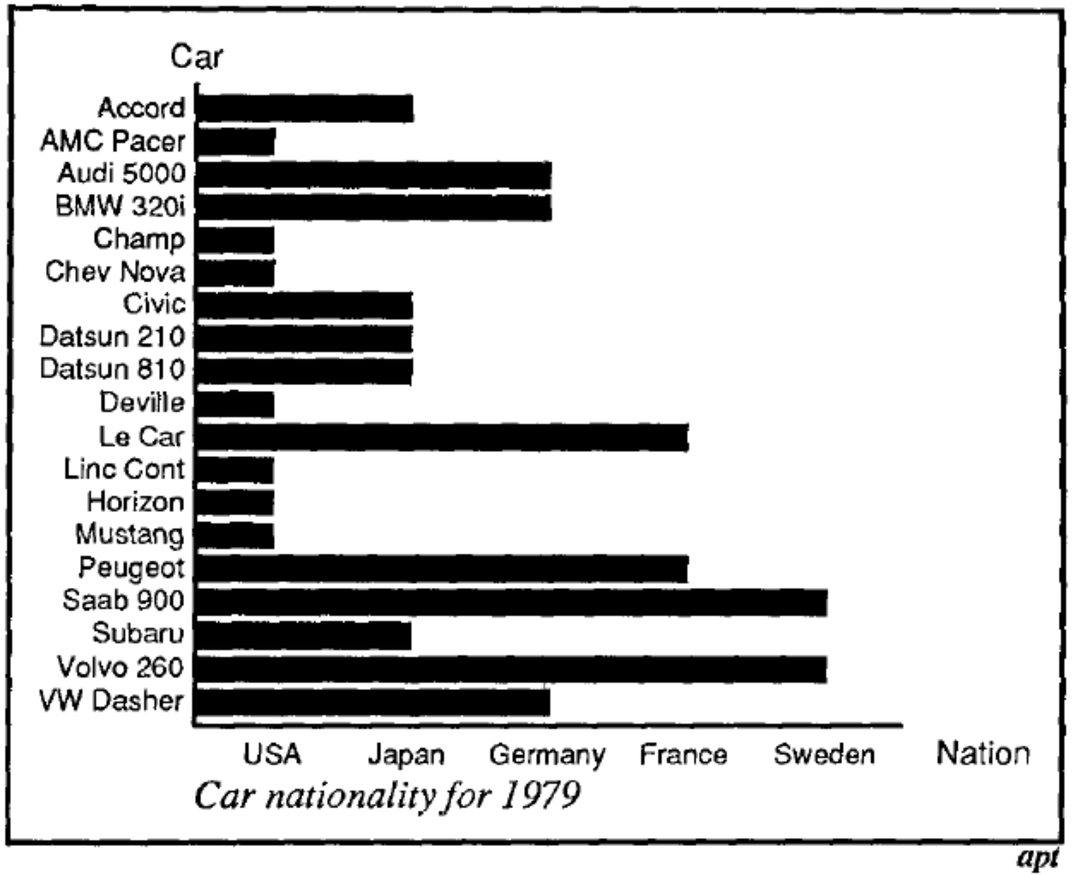


Fig. 11. Incorrect use of a bar chart for the *Nation* relation. The lengths of the bars suggest an ordering on the vertical axis, as if the USA cars were longer or better than the other cars, which is not true for the *Nation* relation.

A length is interpreted as a quantitative value.

Design Criteria

Expressiveness

A set of facts is expressible in a visual language if the sentences (i.e. the visualizations) in the language express all the facts in the set of data, and only the facts in the data.

Effectiveness

[Mackinlay 86]

Design Criteria

Expressiveness

A set of facts is expressible in a visual language if the sentences (i.e. the visualizations) in the language express all the facts in the set of data, and only the facts in the data.

Effectiveness

A visualization is more effective than another visualization if the information conveyed by one visualization is more readily perceived than the information in the other visualization.

[Mackinlay 86]

Design Criteria Translated

Tell the truth and nothing but the truth
(don’t lie, and don’t lie by omission)

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

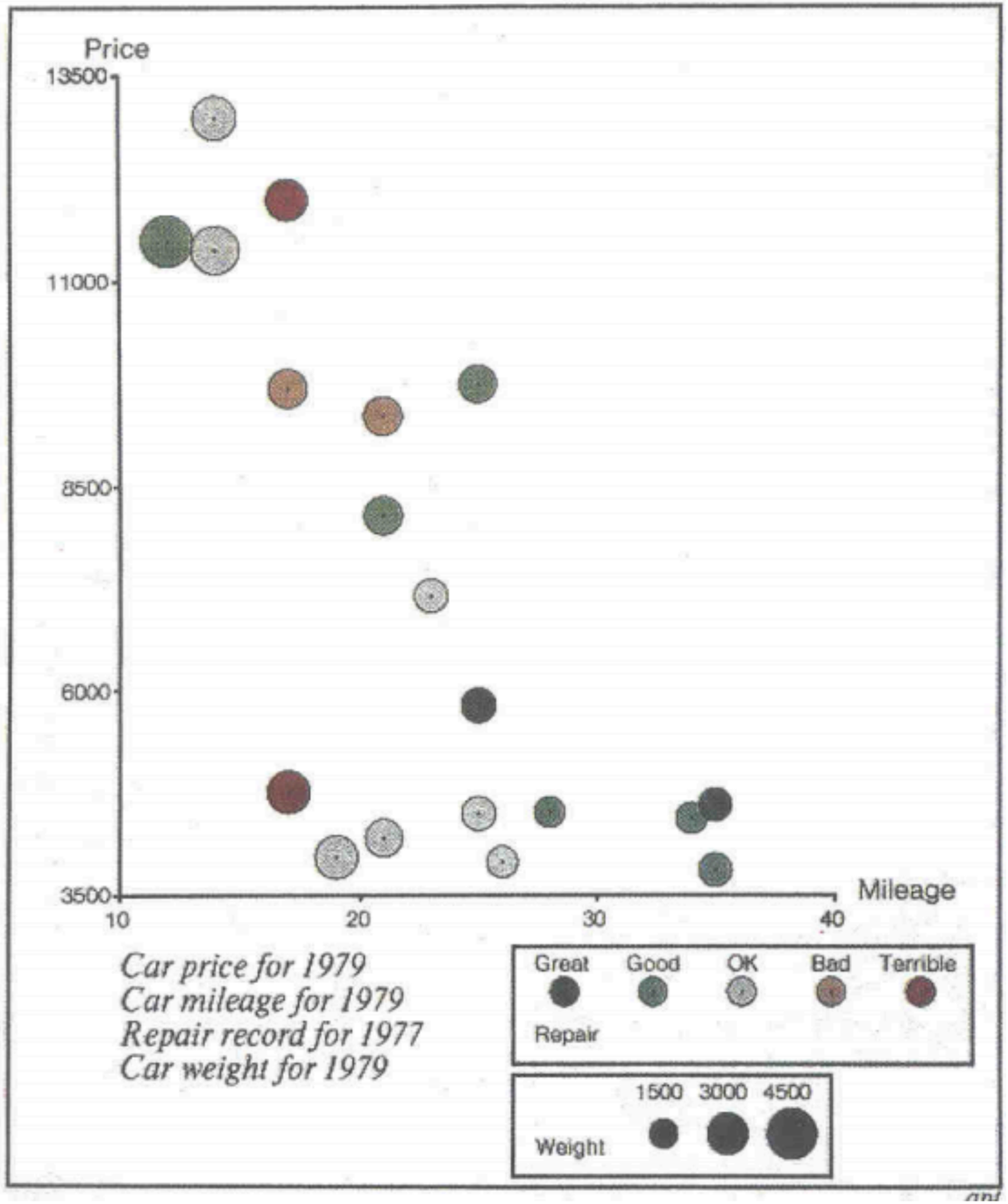
APT searches over design space
- Test expressiveness of each visual encoding
- Generate encodings that pass test
- Rank by perceptual effectiveness criteria

Output the "most effective" visualization

APT

Automatically generate chart for Input variables:

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



Polaris

[Stolte et al 2002]

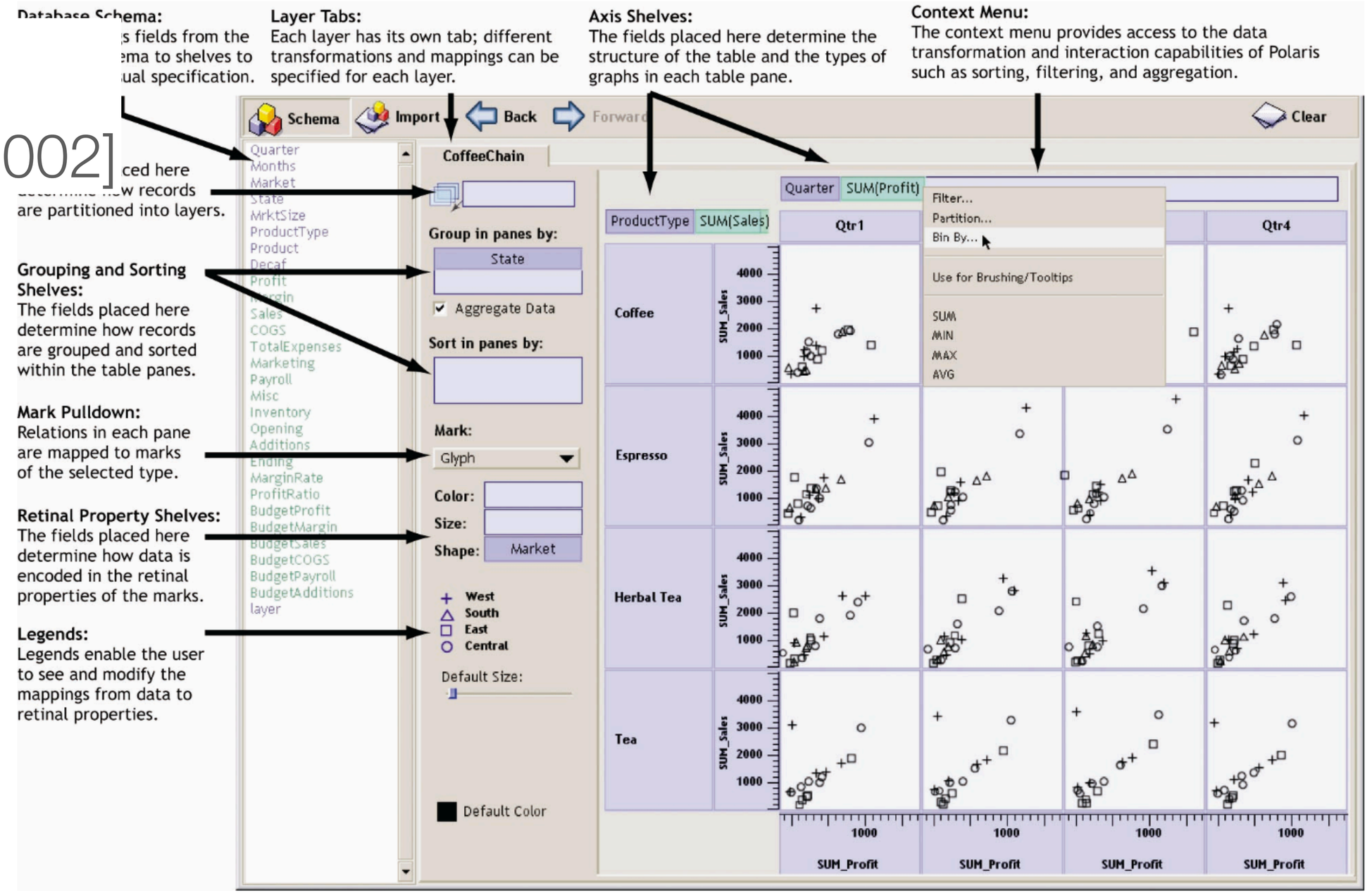
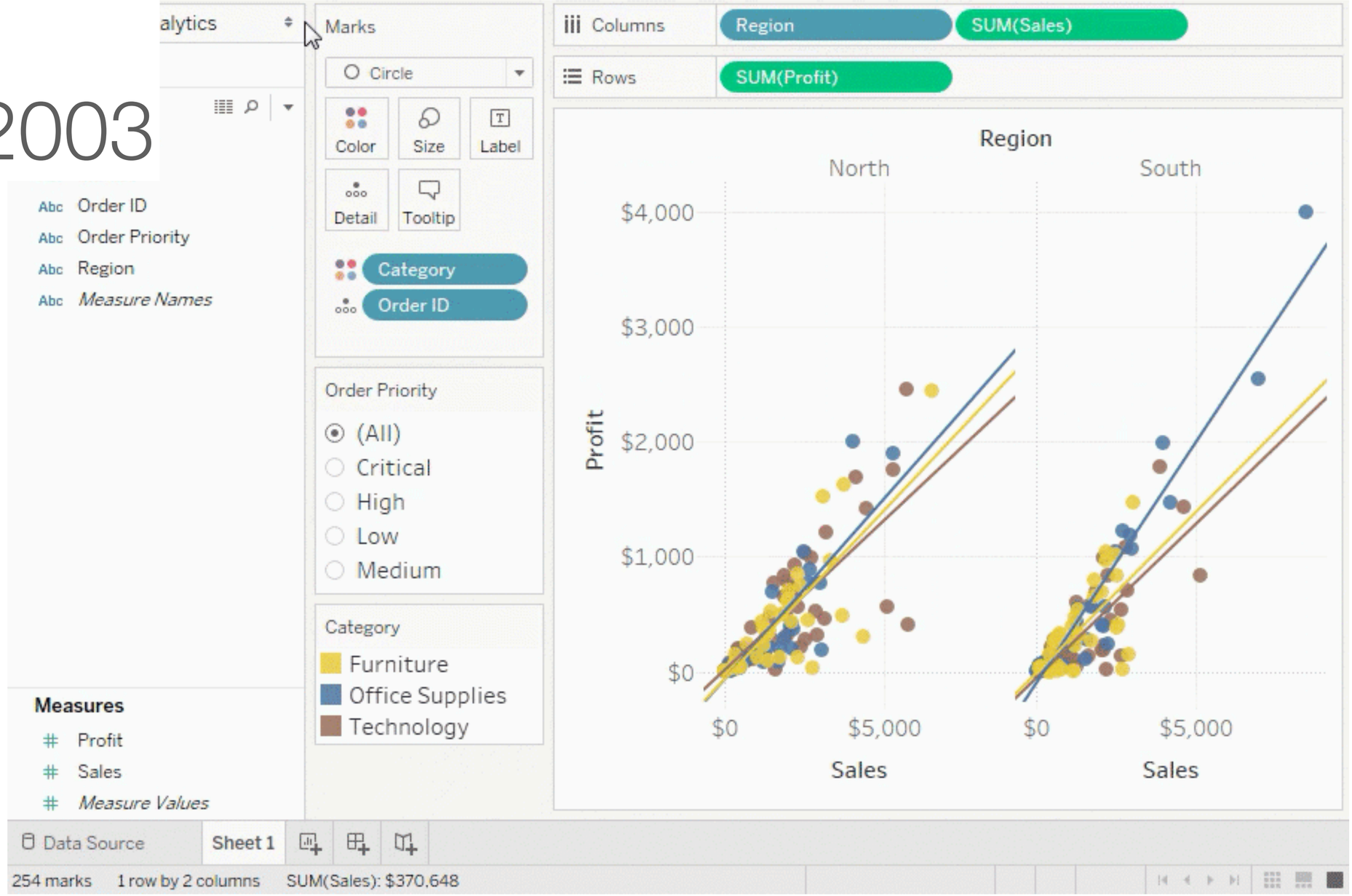


Tableau
founded 2003



Take away: Visual Encoding Design

Use expressive and effective encodings

Avoid over-encoding

Reduce the problem space

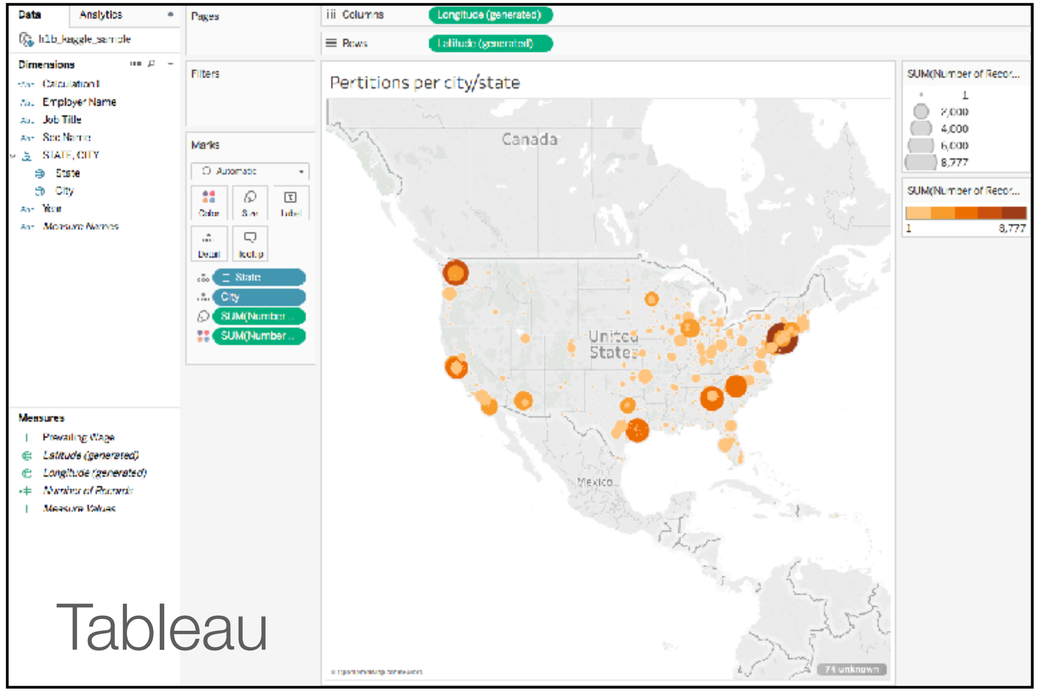
Use space and small multiples intelligently

Use interaction to generate relevant views

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

Next

Exploratory Data Analysis



H-1B petitions filed in each state

10 min break

Download Tableau & H-1B petition data