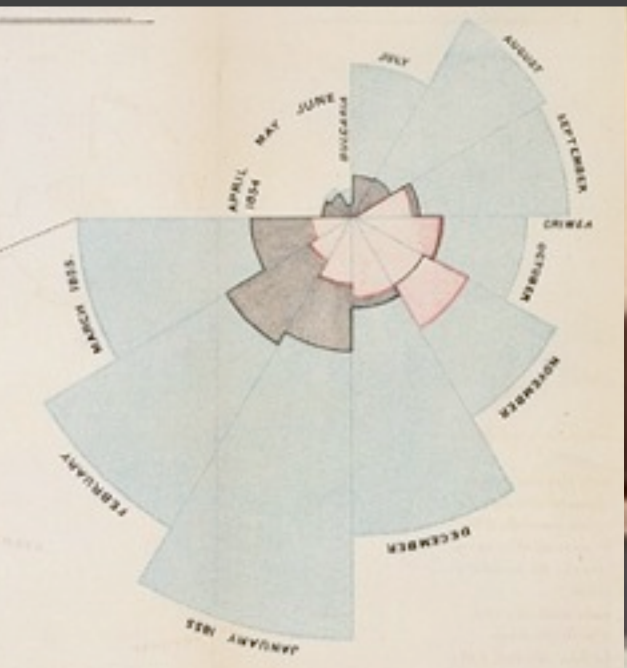
CSE512 :: 9 Jan 2014

Data and Image Models



Jeffrey Heer University of Washington

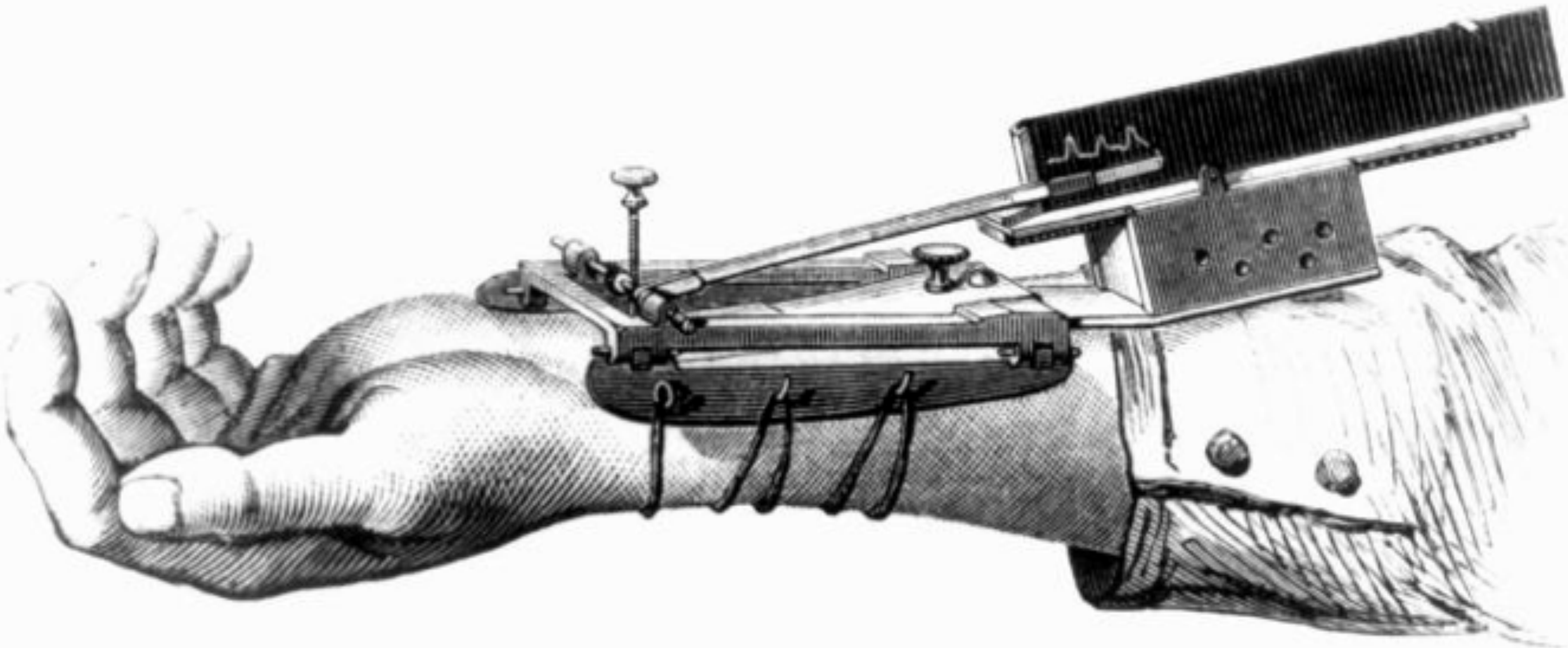
Last Time:
Value of Visualization

The Value of Visualization

Record information
- Blueprints, photographs, seismographs, ...

Analyze data to support reasoning
- Develop and assess hypotheses
- Discover errors in data
- Expand memory
- Find patterns

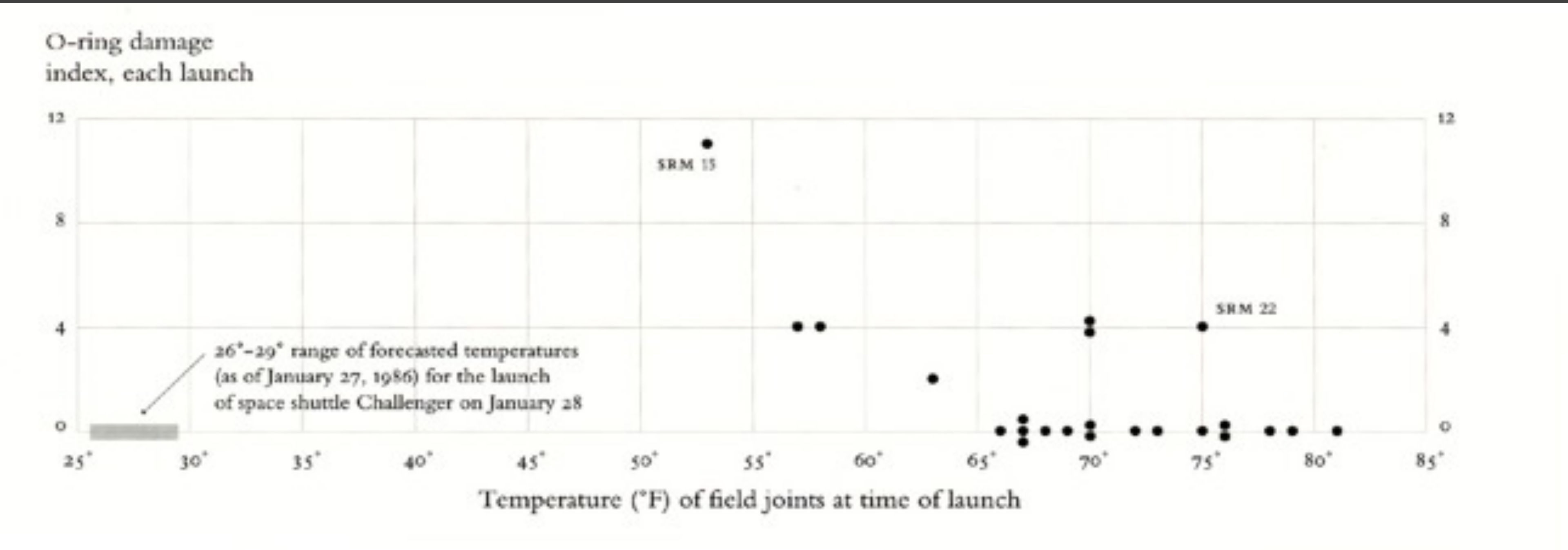
Communicate information to others
- Share and persuade
- Collaborate and revise



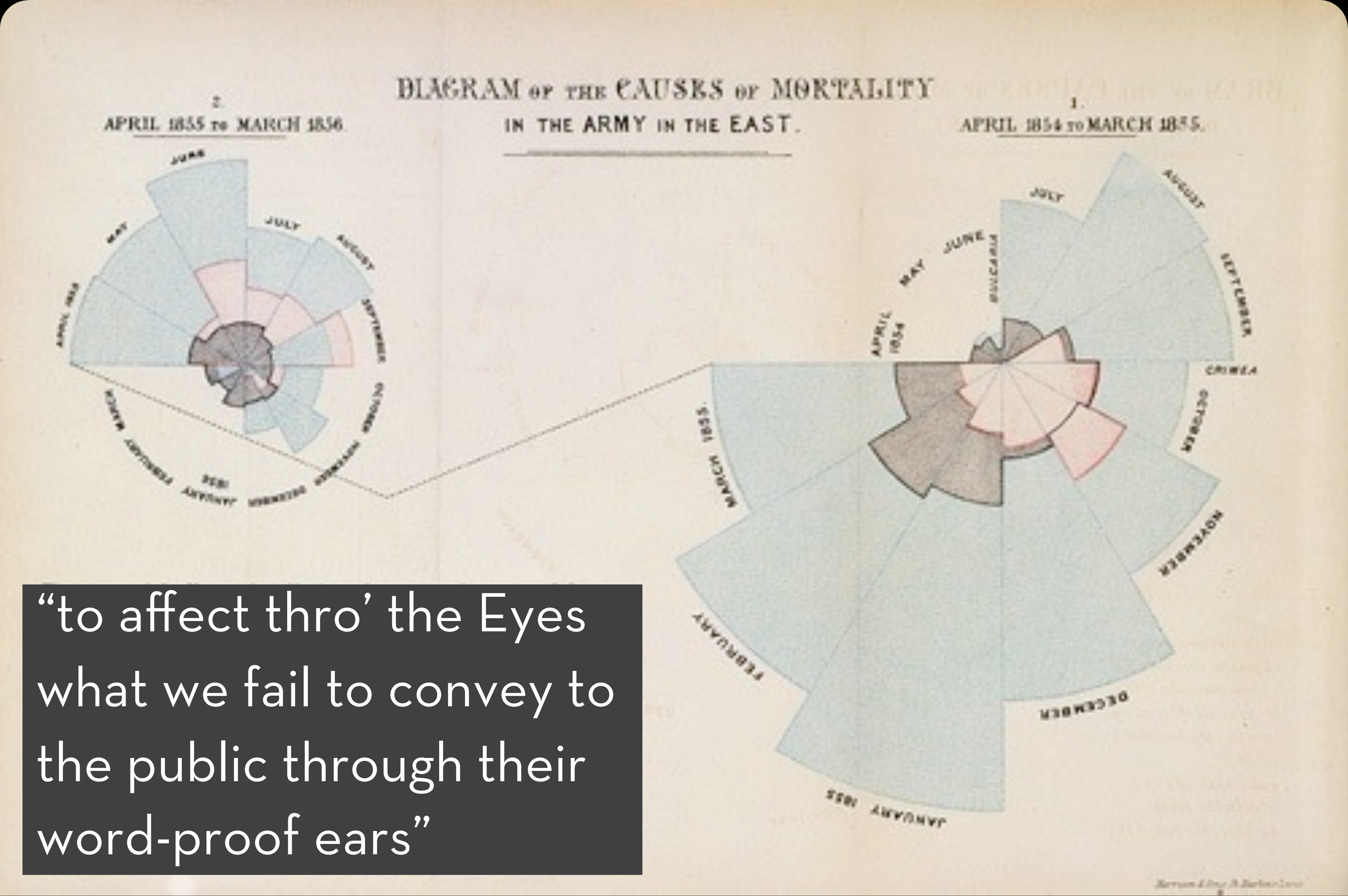
1.
Marey's sphygmograph in use, 1860. *La méthode graphique dans les sciences expérimentales et principalement en physiologie et en médecine.*

Marey's sphygmograph [from Braun 83]

Make a decision: Challenger



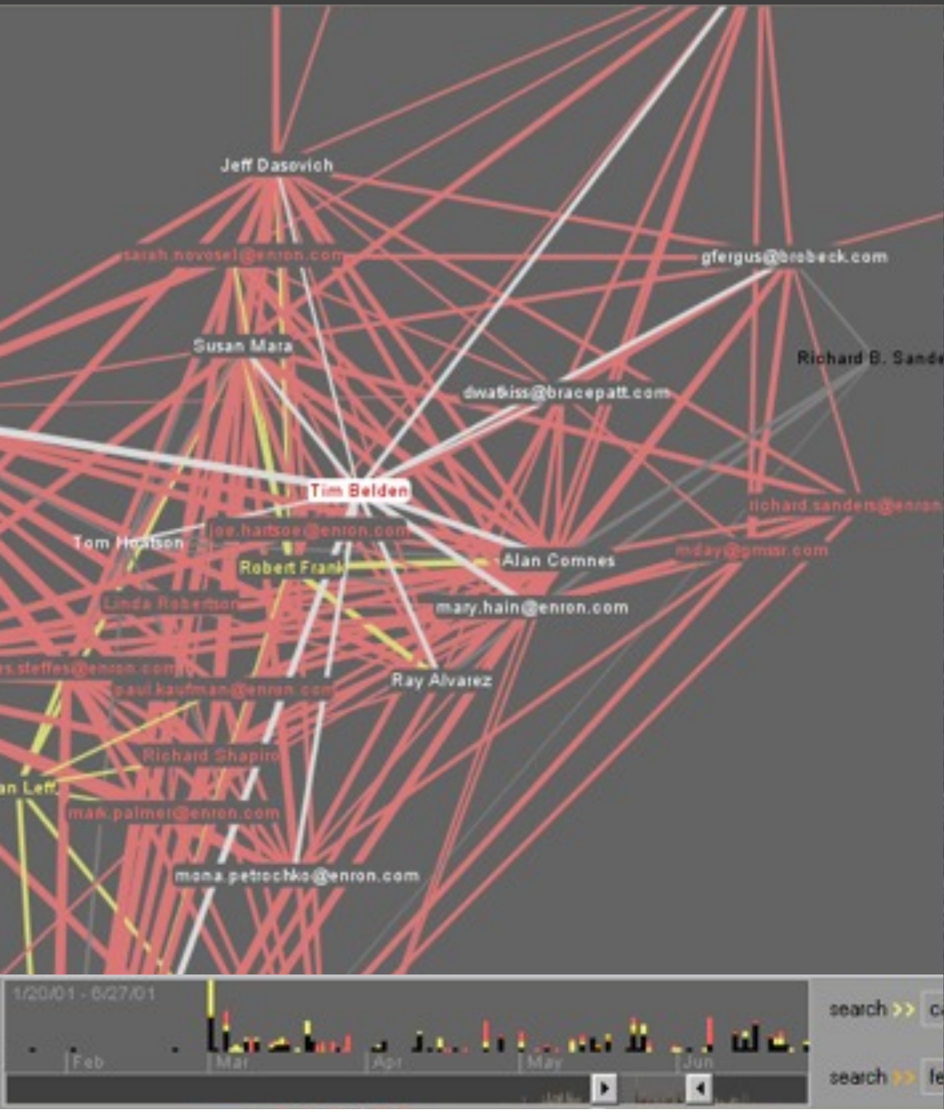
Visualizations drawn by Tufte show how low temperatures damage O-rings [Tufte 97]

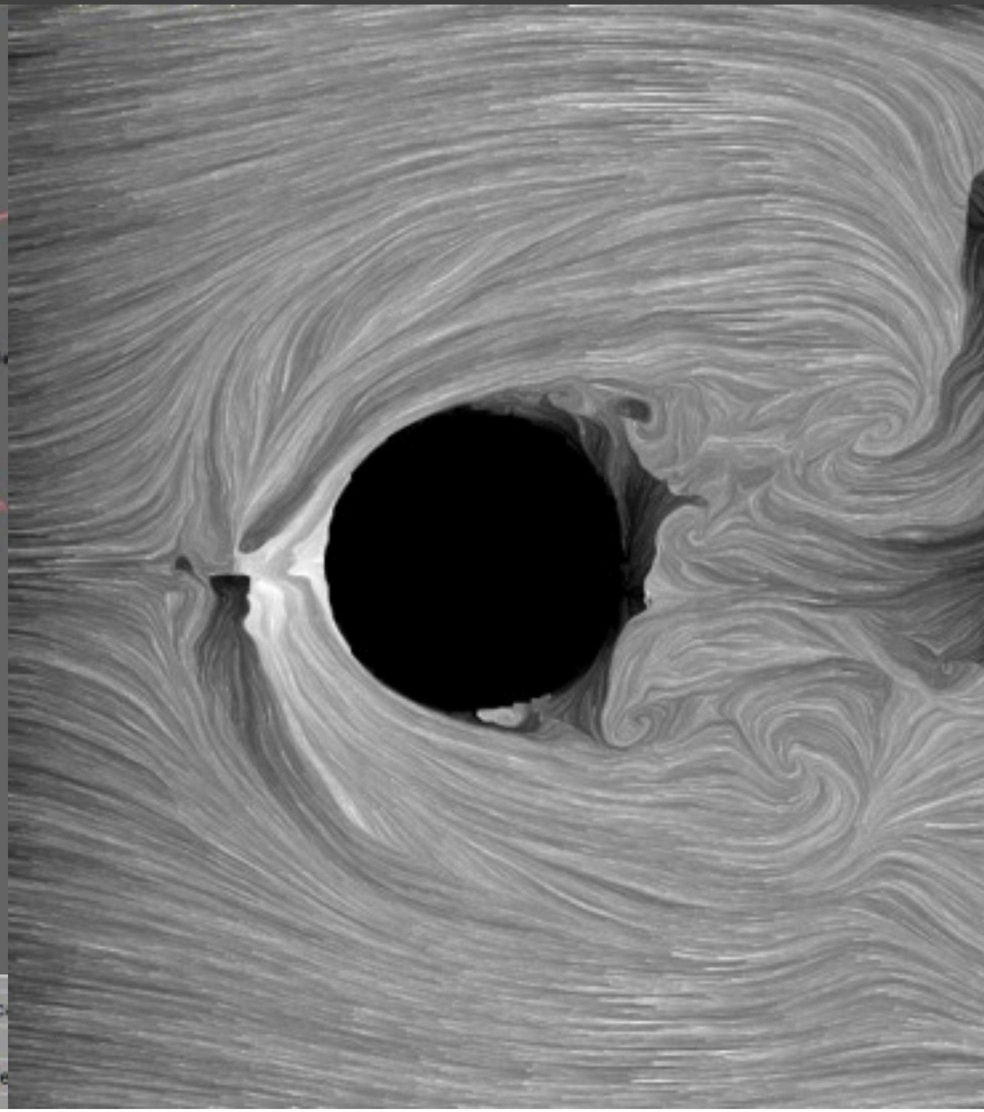


“to affect thro’ the Eyes what we fail to convey to the public through their word-proof ears”

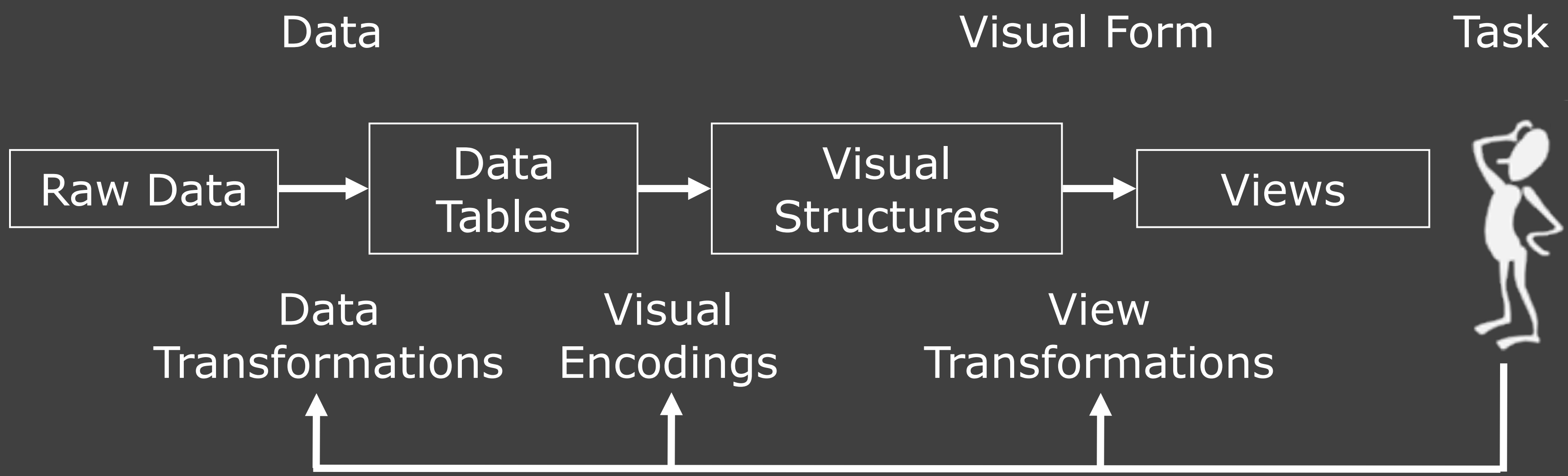
1856 “Coxcomb” of Crimean War Deaths, Florence Nightingale

Info-Vis vs. Sci-Vis?





Visualization Reference Model



Data and Image Models

The Big Picture

task

data
physical type
int, float, etc.
abstract type
nominal, ordinal, etc.

domain
metadata
semantics
conceptual model

processing
algorithms

mapping
visual encoding
visual metaphor

image
visual channel
retinal variables

Topics

Properties of data

Properties of images

Mapping data to images

Data

Data models vs. Conceptual models

Data models are low level descriptions of the data

- Math: Sets with operations on them
- Example: integers with + and × operators

Conceptual models are mental constructions

- Include semantics and support reasoning

Examples (data vs. conceptual)

- (1D floats) vs. Temperature
- (3D vector of floats) vs. Space

Taxonomy (?)

1D (sets and sequences)

Temporal

2D (maps)

3D (shapes)

nD (relational)

Trees (hierarchies)

Networks (graphs)

Are there others?

The eyes have it: A task by data type taxonomy for information visualization [Shneiderman 96]

Types of variables

Physical types

- Characterized by storage format
- Characterized by machine operations

  Example: bool, short, int32, float, double, string, ...

Abstract types

- Provide descriptions of the data
- May be characterized by methods/attributes
- May be organized into a hierarchy

  Example: plants, animals, metazoans, ...

Nominal, Ordinal and Quantitative

N - Nominal (labels)

- Fruits: Apples, oranges, ...

O - Ordered

- Quality of meat: Grade A, AA, AAA

Q - Interval (Location of zero arbitrary)

- Dates: Jan, 19, 2006; Location: (LAT 33.98, LONG -118.45)
- Like a geometric point. Cannot compare directly
- Only differences (i.e. intervals) may be compared

Q - Ratio (zero fixed)

- Physical measurement: Length, Mass, Temp, ...
- Counts and amounts
- Like a geometric vector, origin is meaningful

S. S. Stevens, On the theory of scales of measurements, 1946

Nominal, Ordinal and Quantitative

N - Nominal (labels)

- Operations: =, ≠

O - Ordered

- Operations: =, ≠, <, >

Q - Interval (Location of zero arbitrary)

- Operations: =, ≠, <, >, -
- Can measure distances or spans

Q - Ratio (zero fixed)

- Operations: =, ≠, <, >, -, %
- Can measure ratios or proportions

S. S. Stevens, On the theory of scales of measurements, 1946

From data model to N,O,Q data type

Data model

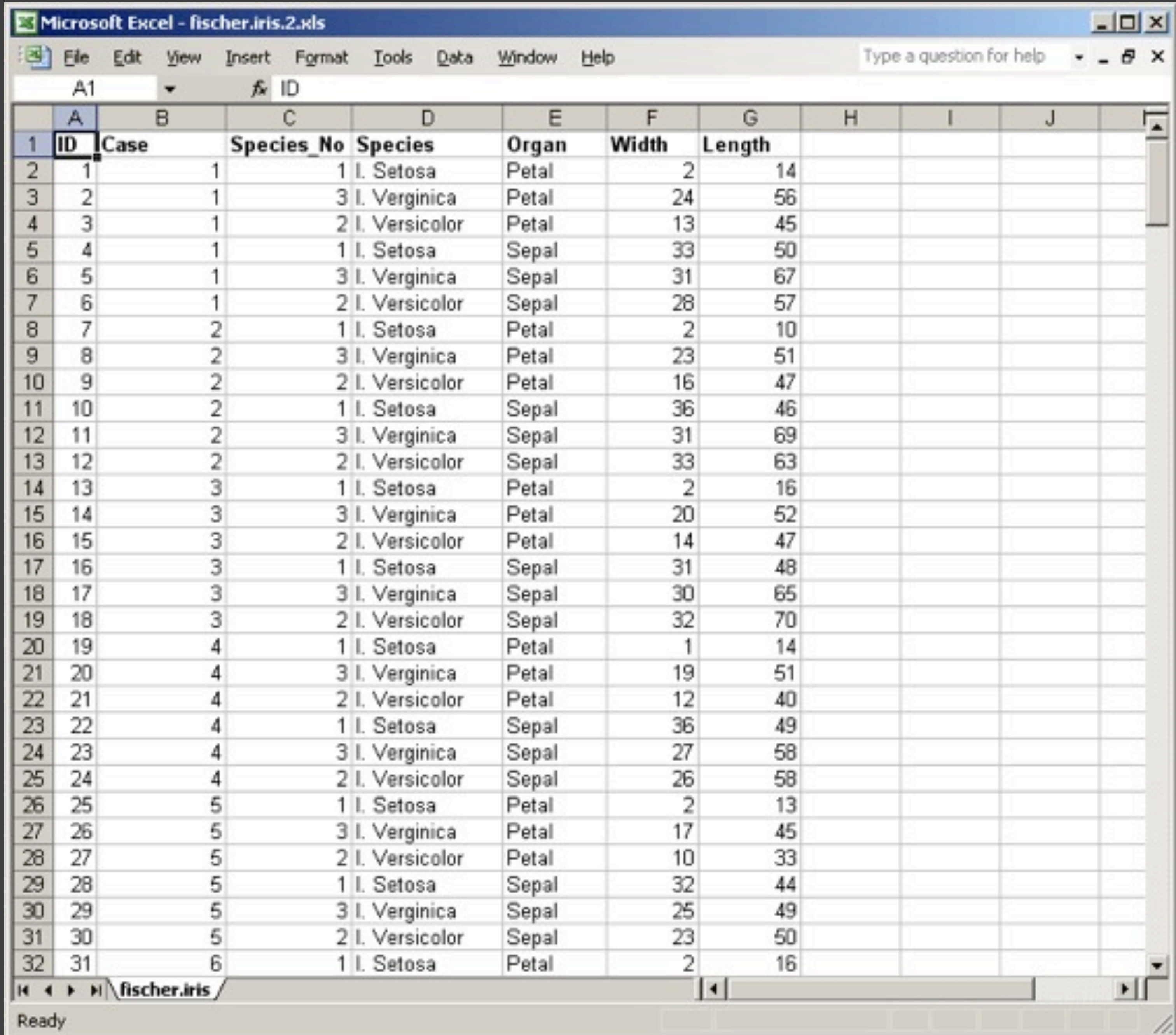
- 32.5, 54.0, -17.3, …
- floats

Conceptual model

- Temperature (°C)

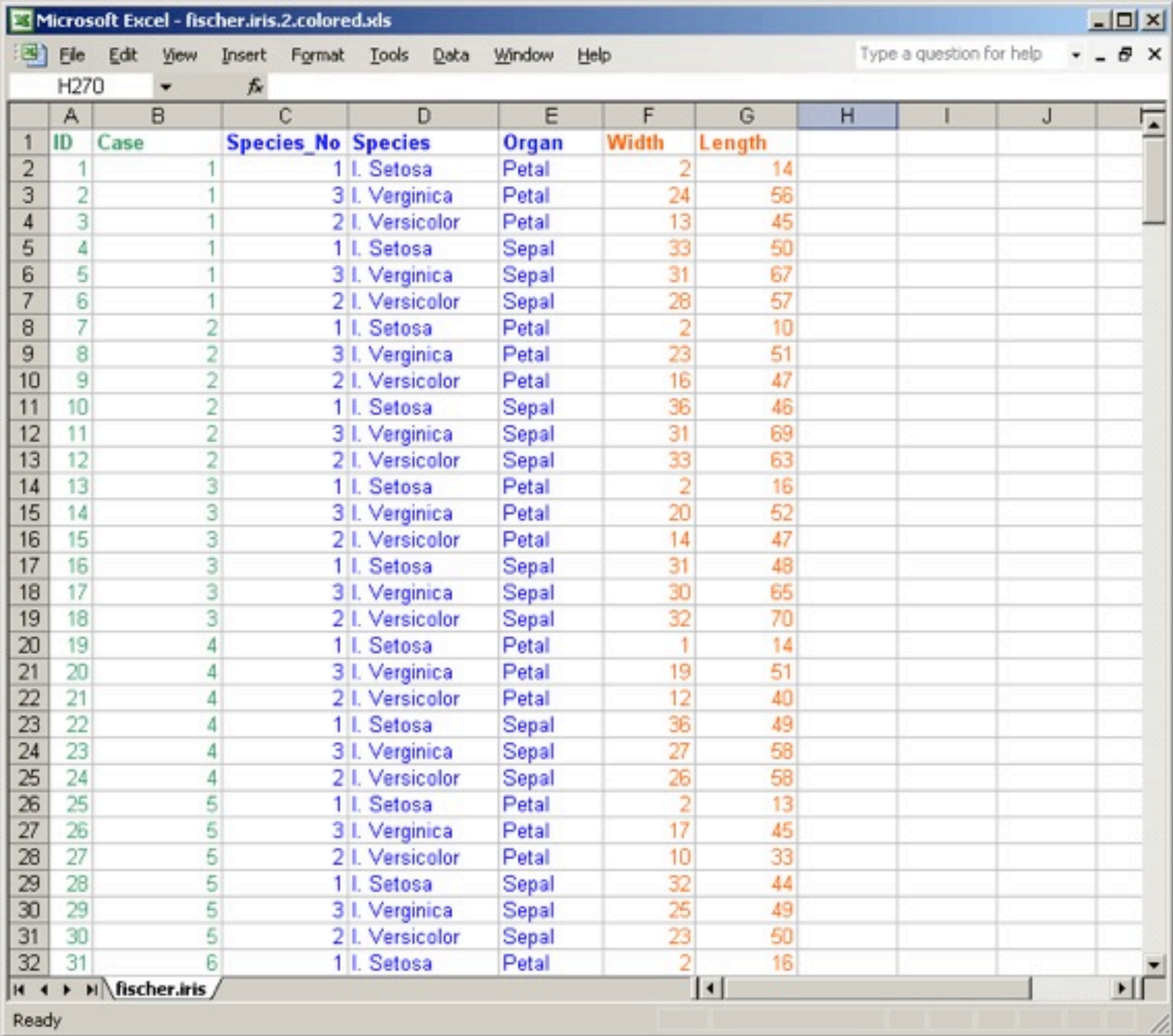
Data type

- Burned vs. Not burned (N)
- Hot, warm, cold (O)
- Continuous range of values (Q)



ID	Case	Species_No	Species	Organ	Width	Length
1	1	1	I. Setosa	Petal	2	14
2	1	3	I. Verginica	Petal	24	56
3	1	2	I. Versicolor	Petal	13	45
4	1	1	I. Setosa	Sepal	33	50
5	1	3	I. Verginica	Sepal	31	67
6	1	2	I. Versicolor	Sepal	28	57
7	2	1	I. Setosa	Petal	2	10
8	2	3	I. Verginica	Petal	23	51
9	2	2	I. Versicolor	Petal	16	47
10	2	1	I. Setosa	Sepal	36	46
11	2	3	I. Verginica	Sepal	31	69
12	2	2	I. Versicolor	Sepal	33	63
13	3	1	I. Setosa	Petal	2	16
14	3	3	I. Verginica	Petal	20	52
15	3	2	I. Versicolor	Petal	14	47
16	3	1	I. Setosa	Sepal	31	48
17	3	3	I. Verginica	Sepal	30	65
18	3	2	I. Versicolor	Sepal	32	70
19	4	1	I. Setosa	Petal	1	14
20	4	3	I. Verginica	Petal	19	51
21	4	2	I. Versicolor	Petal	12	40
22	4	1	I. Setosa	Sepal	36	49
23	4	3	I. Verginica	Sepal	27	58
24	4	2	I. Versicolor	Sepal	26	58
25	5	1	I. Setosa	Petal	2	13
26	5	3	I. Verginica	Petal	17	45
27	5	2	I. Versicolor	Petal	10	33
28	5	1	I. Setosa	Sepal	32	44
29	5	3	I. Verginica	Sepal	25	49
30	5	2	I. Versicolor	Sepal	23	50
31	6	1	I. Setosa	Petal	2	16

Sepal and petal lengths and widths for three species of iris [Fisher 1936].


Microsoft Excel - fischer.iris.2.colored.xls

ID	Case	Species_No	Species	Organ	Width	Length
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30	5	2	I. Versicolor	Sepal	23	50
31	6	1	I. Setosa	Petal	2	16

fischer.iris

Q

O

N

Relational data model

Represent data as a **table** (*relation*)

Each **row** (*tuple*) represents a single record

- Each record is a fixed-length tuple

Each **column** (*attribute*) represents a single *variable*

- Each attribute has a *name* and a *data type*

A table's **schema** is the set of names and data types

A **database** is a collection of tables (relations)

Relational Algebra [Codd]

- Data transformations (sql)
- Projection (select)
- Selection (where)
- Sorting (order by)
- Aggregation (group by, sum, min, ...)
- Set operations (union, ...)
- Combine (inner join, outer join, ...)

Statistical data model

Variables or measurements

Categories or factors or dimensions

Observations or cases

Statistical data model

Variables or measurements

Categories or factors or dimensions

Observations or cases

Month	Control	Placebo	300 mg	450 mg
March	165	163	166	168
April	162	159	161	163
May	164	158	161	153
June	162	161	158	160
July	166	158	160	148
August	163	158	157	150

Blood Pressure Study (4 treatments, 6 months)

Dimensions and Measures

Dimensions: Discrete variables describing data
Dates, categories of values (independent vars)

Measures: Data values that can be aggregated
Numbers to be analyzed (dependent vars)
Aggregate as sum, count, average, std. deviation

Example: U.S. Census Data

People: # of people in group

Year: 1850 – 2000 (every decade)

Age: 0 – 90+

Sex: Male, Female

Marital Status: Single, Married, Divorced, …

Example: U.S. Census

People

Year

Age

Sex

Marital Status

2348 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
30	1850	70	0	1	73677
31	1850	70	0	2	71762
32	1850	75	0	1	40834
33	1850	75	0	2	40229
34	1850	80	0	1	23449
35	1850	80	0	2	22949
36	1850	85	0	1	8186
37	1850	85	0	2	10511
38	1850	90	0	1	5259
39	1850	90	0	2	6569
40	1860	0	0	1	2120846
41	1860	0	0	2	2092162

Census: N, O, Q?

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

Census: Dimension or Measure?

People Count	Measure
Year	Dimension
Age	Depends!
Sex (M/F)	Dimension
Marital Status	Dimension

Roll-Up and Drill-Down

Want to examine marital status in each decade?

Roll-up the data along the desired dimensions

Dimensions (year, marst) — Measure (sum(people))

```
SELECT year, marst, sum(people)
FROM census
GROUP BY year, marst;
```

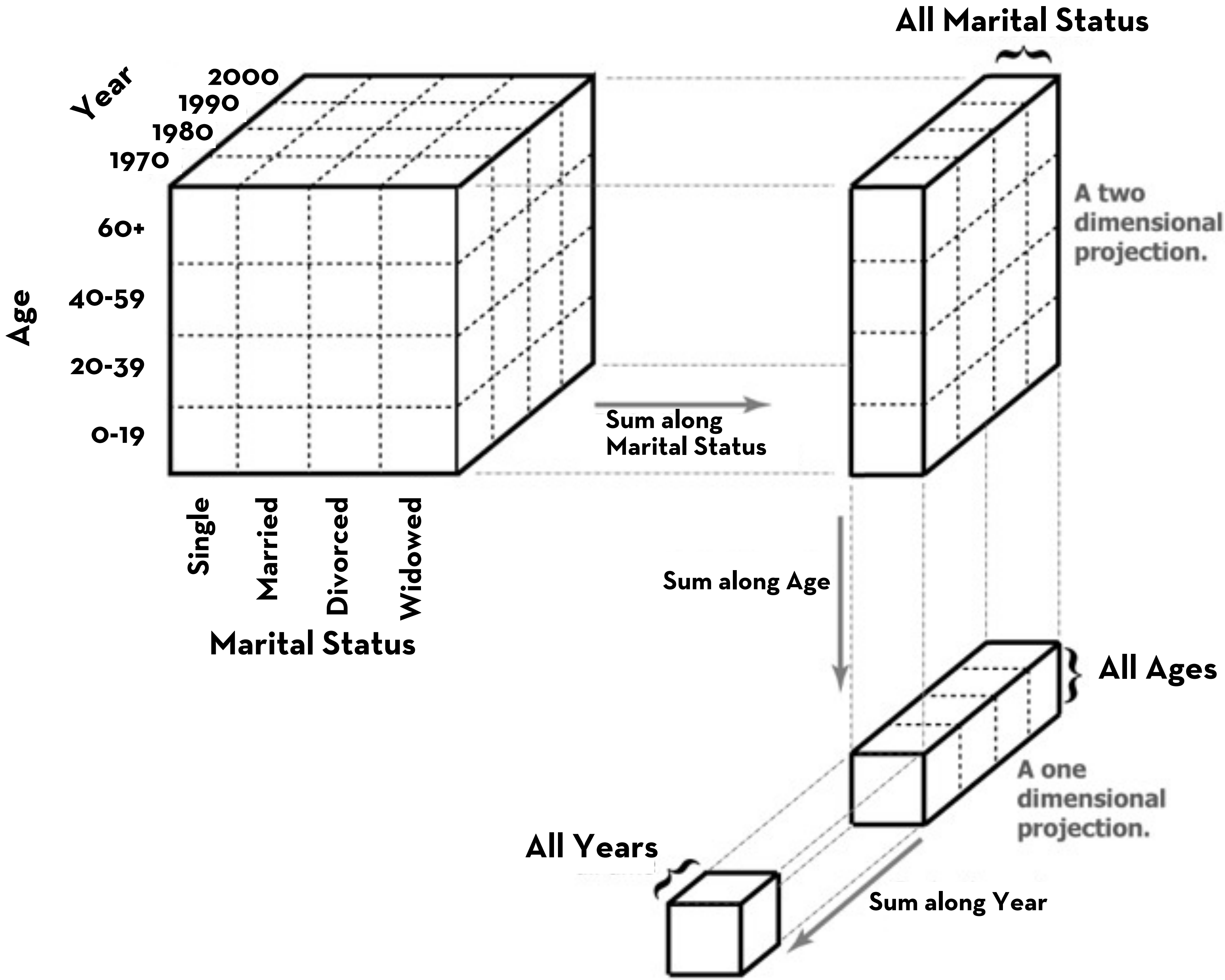
Dimensions (year, marst)

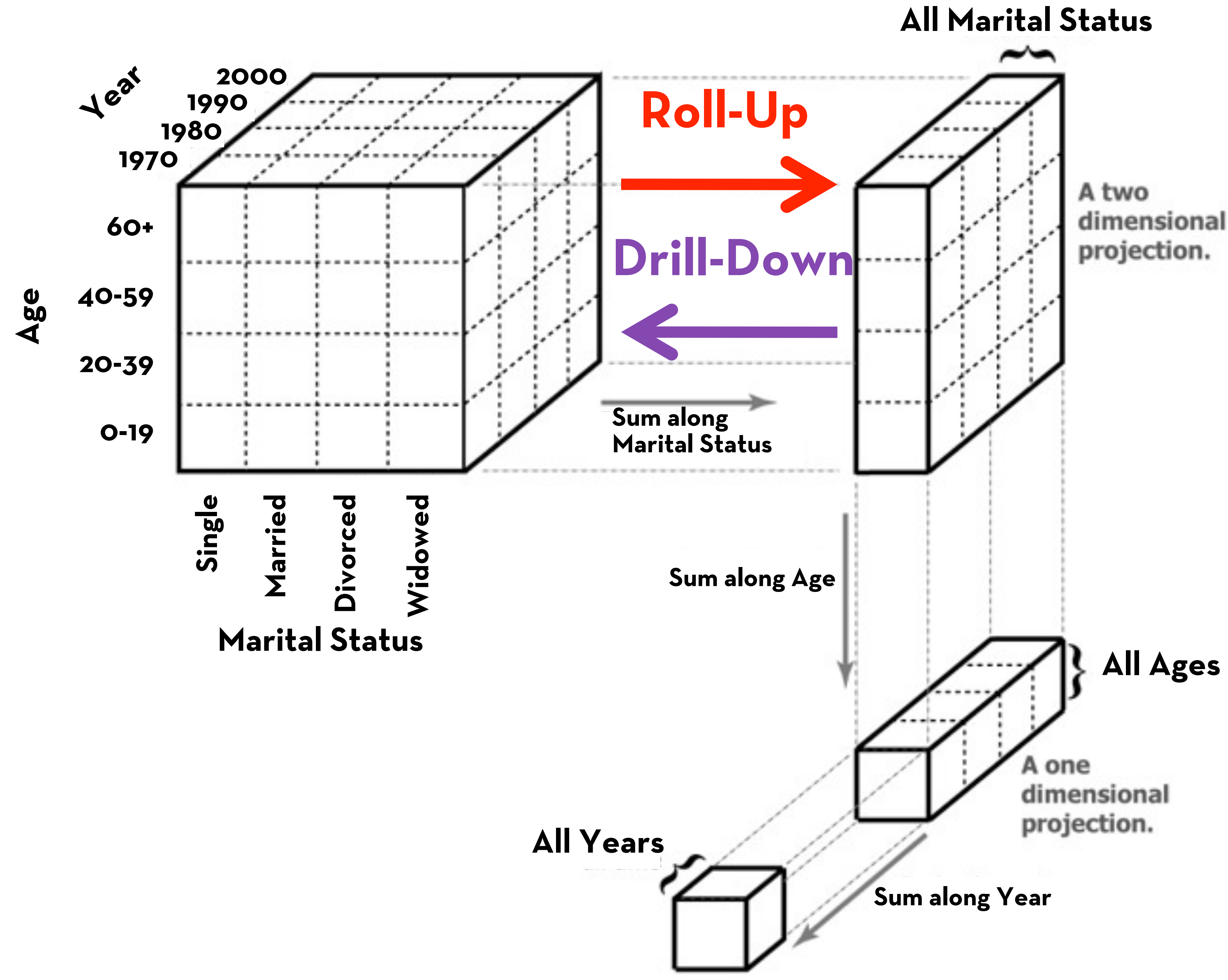
Roll-Up and Drill-Down

Need more detailed information?

Drill-down into additional dimensions

```
SELECT year, age, marst, sum(people)
FROM census
GROUP BY year, age, marst;
```


All Marital Status
Year
2000
1990
1980
1970
Age
60+
40-59
20-39
0-19
Single
Married
Divorced
Widowed
Marital Status
A two dimensional projection.
Sum along Marital Status
Sum along Age
All Ages
A one dimensional projection.
All Years
Sum along Year


All Marital Status
Year
2000
1990
1980
1970
Roll-Up
Drill-Down
A two dimensional projection.
Age
60+
40-59
20-39
0-19
Sum along Marital Status
Single
Married
Divorced
Widowed
Marital Status
Sum along Age
All Ages
A one dimensional projection.
All Years
Sum along Year

YEAR	AGE	MARST	SEX	PEOPLE
1850	0	0	1	1,483,789
1850	5	0	1	1,411,067
1860	0	0	1	2,120,846
1860	5	0	1	1,804,467
. . .				

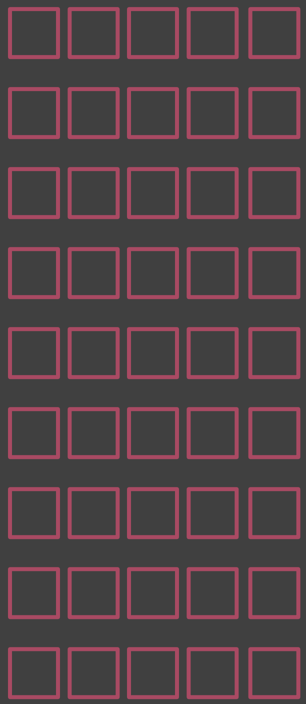
AGE	MARST	SEX	1850	1860	. . .
0	0	1	1,483,789	2,120,846	. . .
5	0	1	1,411,067	1,804,467	. . .
. . .					

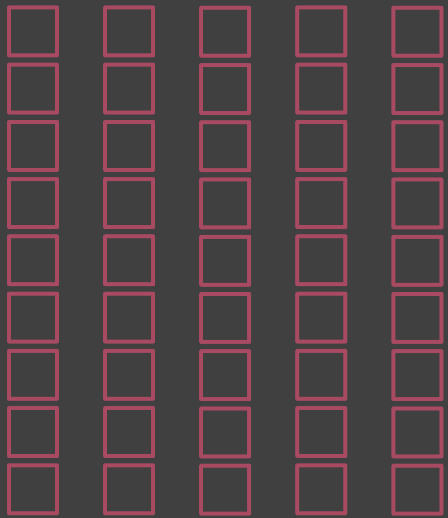
Which format might we prefer?

Row vs. Column-Oriented Databases

Relational Data Organizations

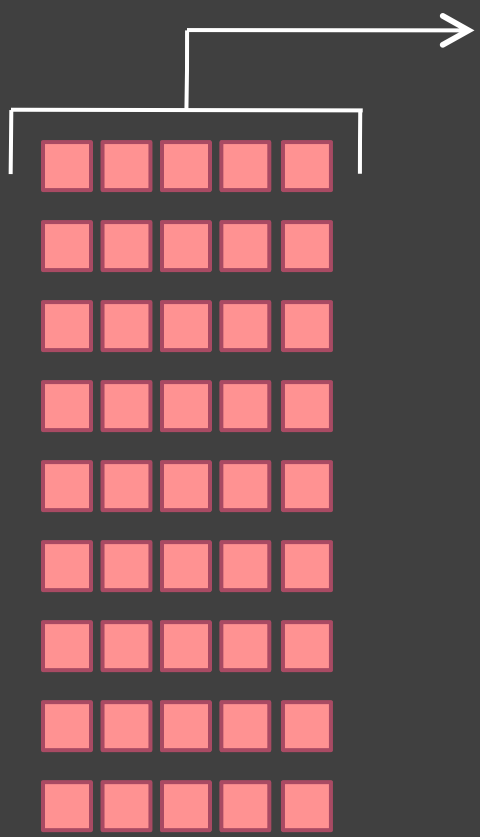
Transactions	vs.	**Analysis**
Row-oriented		Column-oriented



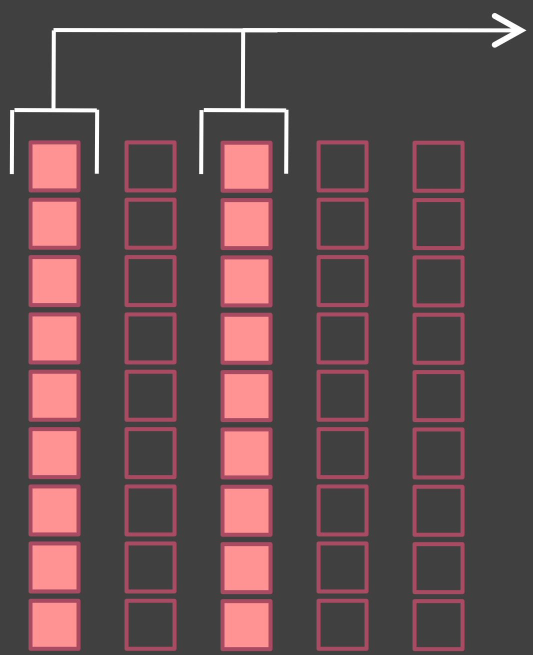


Relational Data Organizations

Row-oriented



Column-oriented



Relational Data Organizations

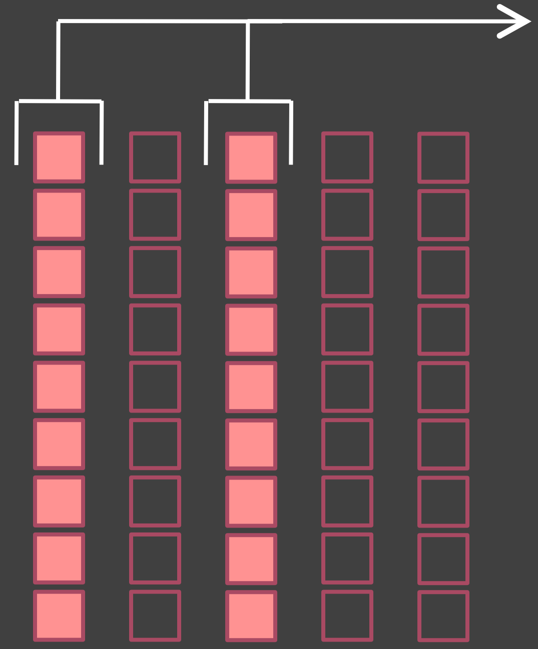
Speed-up Analysis

Reduce data transfer

Improved locality

Data compression

Column-oriented



Administrivia

Announcements

Auditors

- Requirements: Come to class and participate (online as well)

Class participation requirements

- Complete readings before class
- In-class discussion
- Post at least 1 discussion substantive comment/question on Piazza within 24 hours after each lecture (11am next day)

Assignment 1: Visualization Design

Design a static visualization for a given data set.

Deliverables (submit via Catalyst)

- Image of your visualization
- Short description and design rationale (≤ 4 para.)

Due by ***5:00pm*** on **Monday 1/13**.

Questions?

Image

Visual language is a sign system

Jacques Bertin

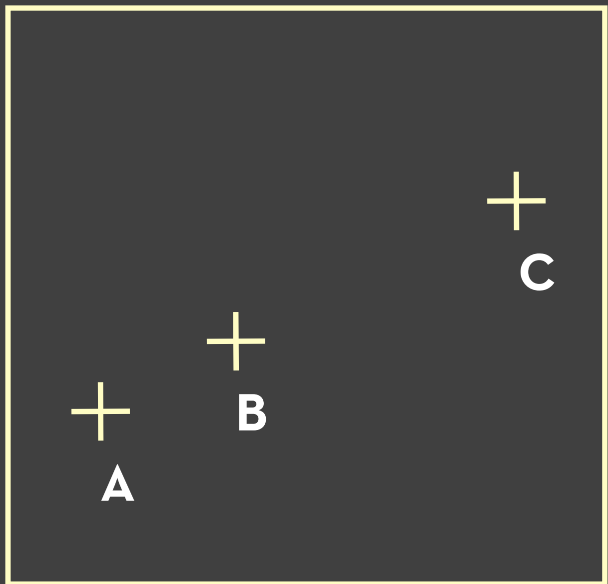
Images perceived as a set of signs

Sender encodes information in signs

Receiver decodes information from signs

Sémiologie Graphique, 1967

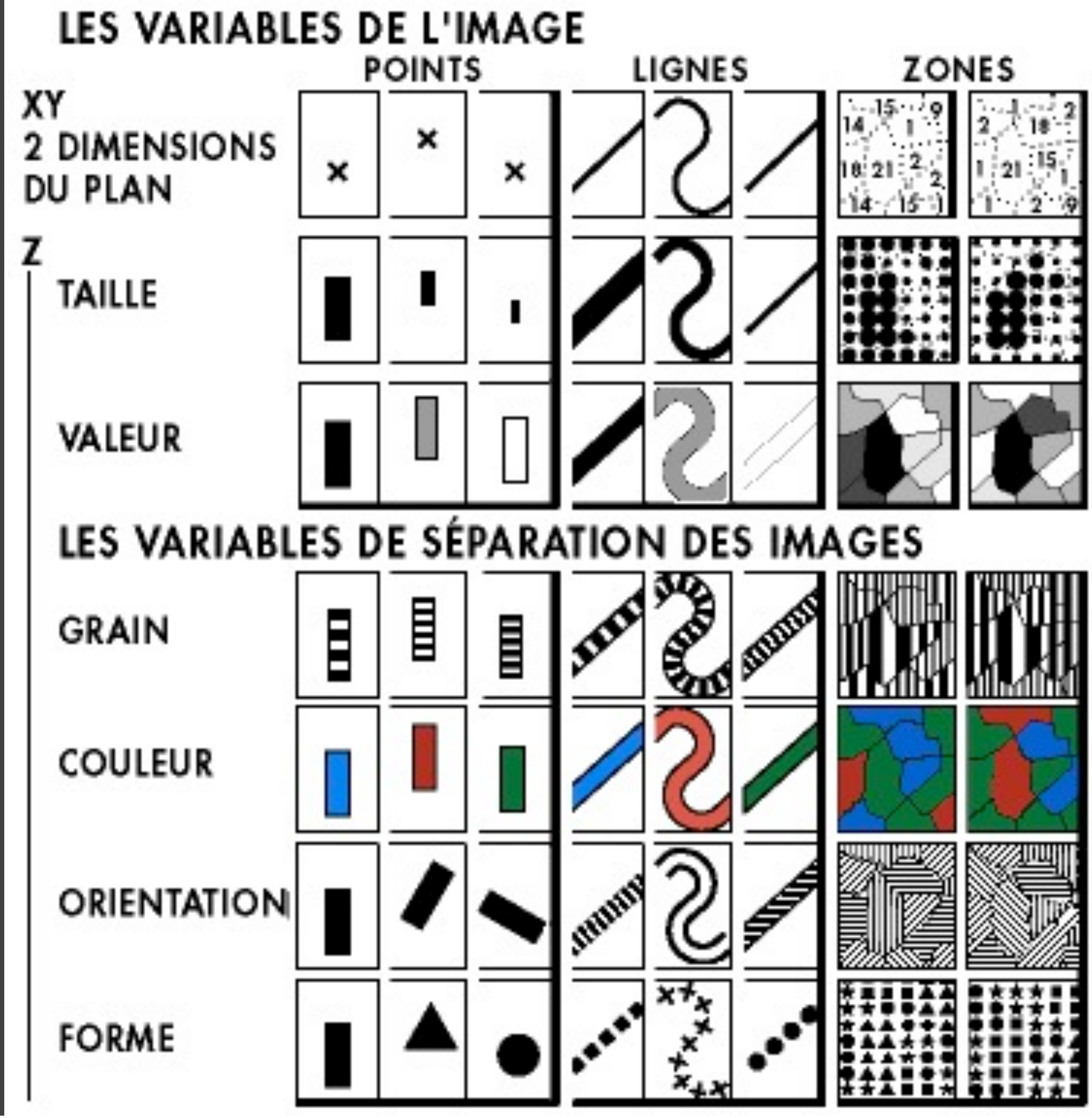
Bertin's Semiology of Graphics



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

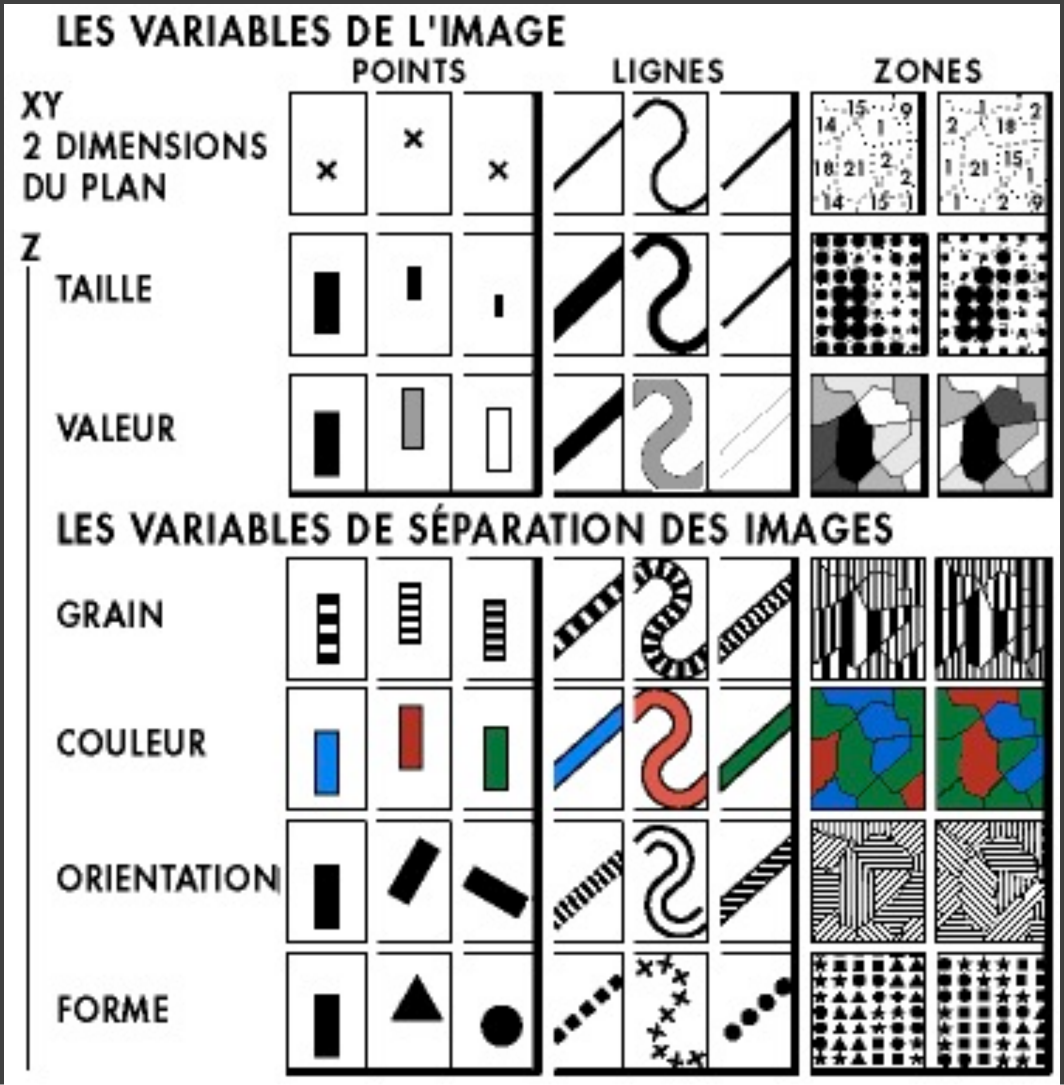
∴ Encode quantitative variables

"Resemblance, order and proportion are the three signifieds in graphics." - Bertin


LES VARIABLES DE L'IMAGE
POINTS
LIGNES
ZONES
XY
2 DIMENSIONS
DU PLAN
Z
TAILLE
VALEUR
LES VARIABLES DE SÉPARATION DES IMAGES
GRAIN
COULEUR
ORIENTATION
FORME

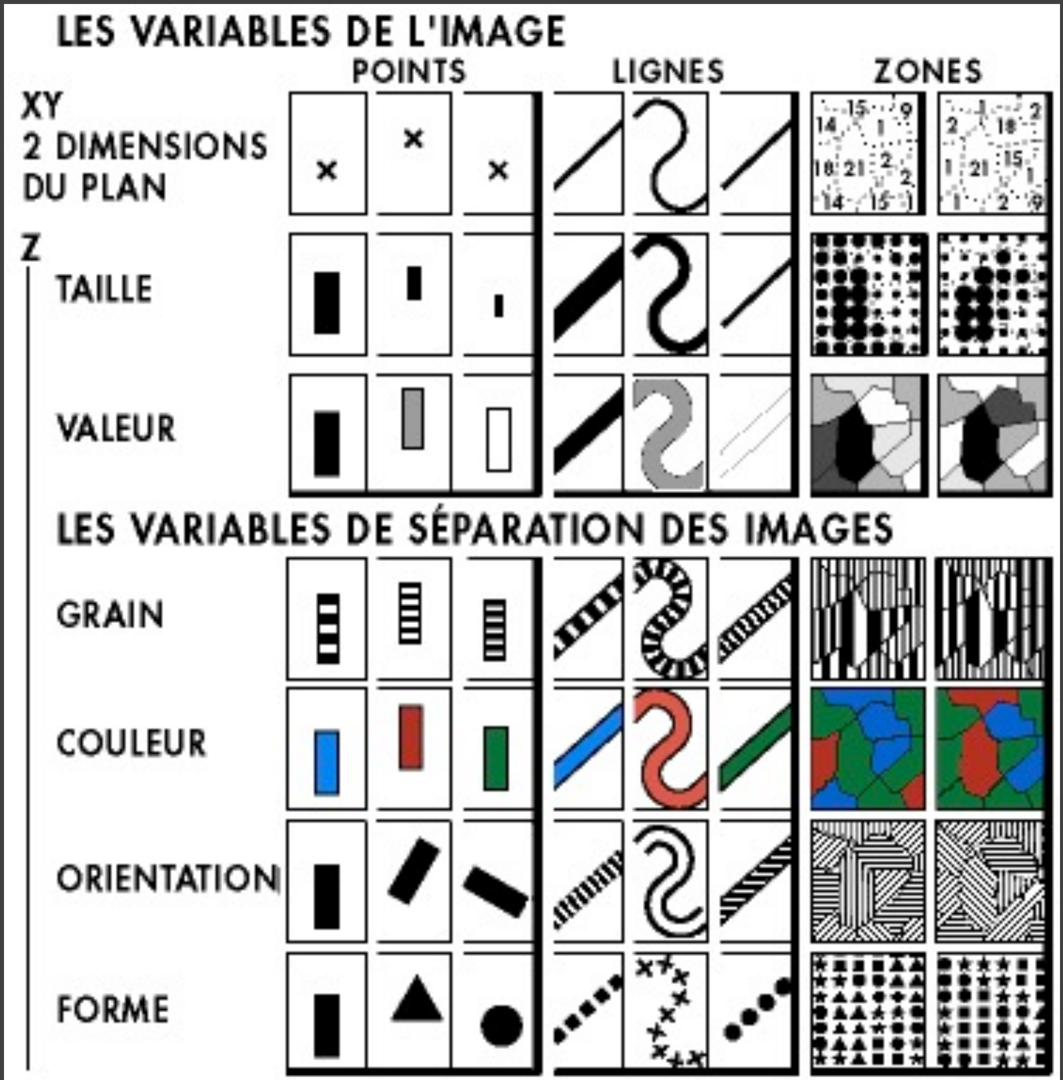
Visual encoding variables

Position (x 2)
Size
Value
Texture
Color
Orientation
Shape



Visual encoding variables

Position
Length
Area
Volume
Value
Texture
Color
Orientation
Shape
Transparency
Blur / Focus ...

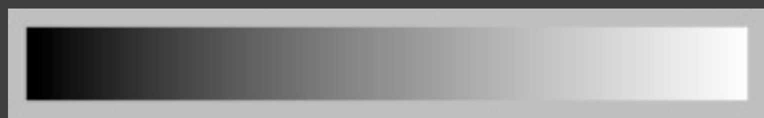


Information in color and value

Value is perceived as ordered

∴ Encode ordinal variables (O)

∴ Encode continuous variables (Q) [not as well]



Hue is normally perceived as unordered

∴ Encode nominal variables (N) using color

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

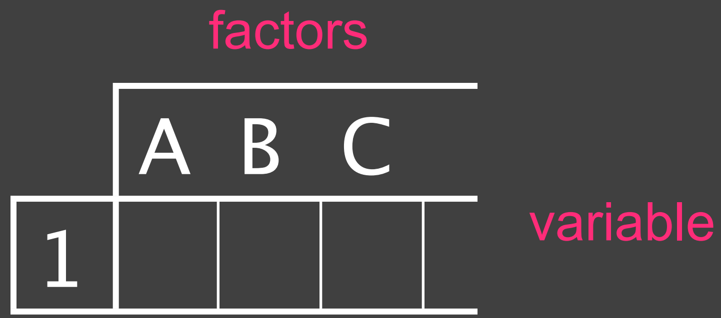
Ordered

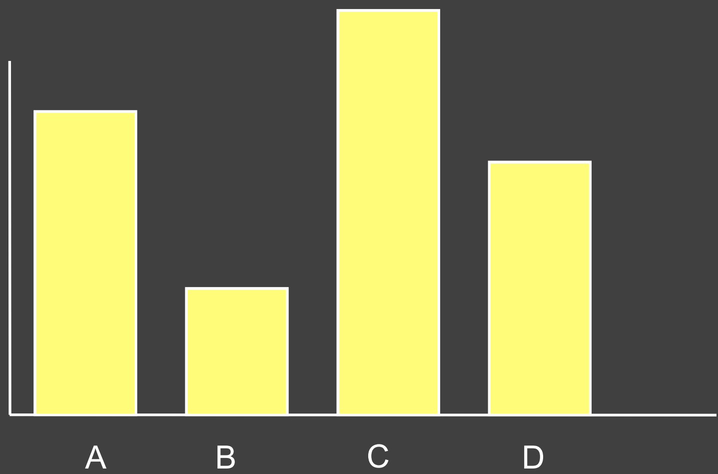
Quantitative

Note: **Q < O < N**

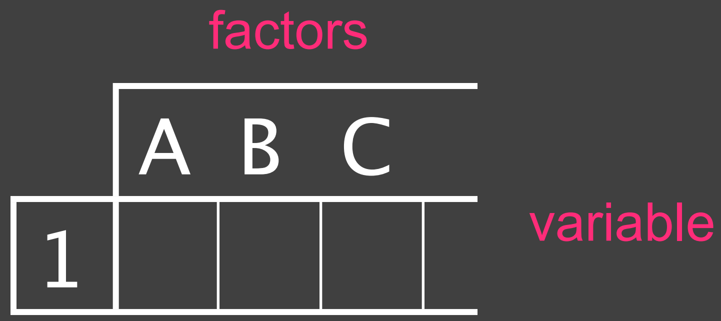
Design Space of Visual Encodings

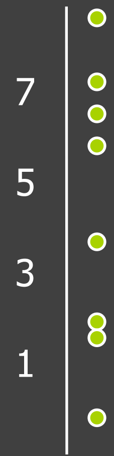
Univariate data

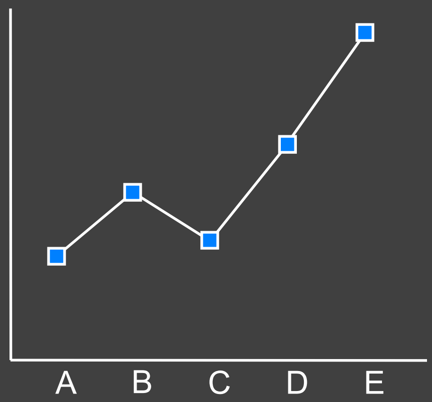


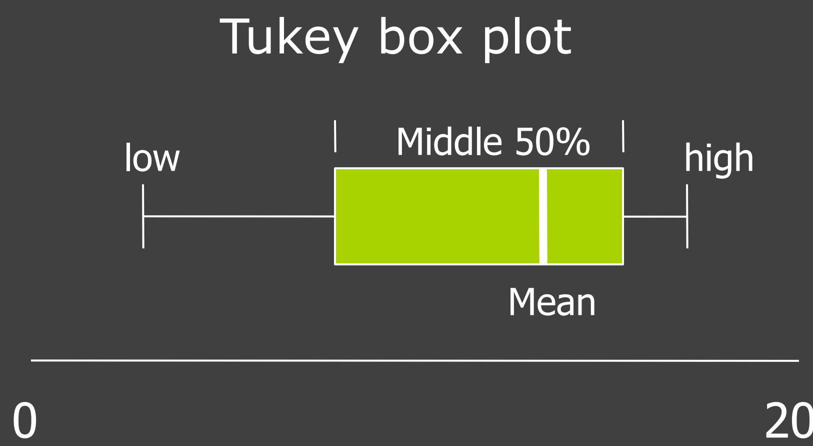


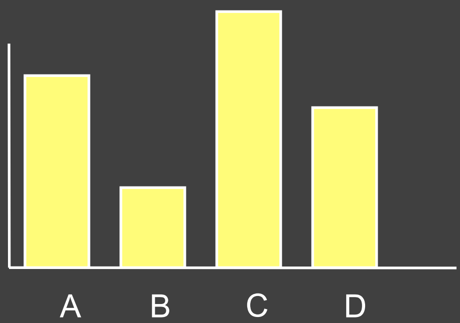
Univariate data





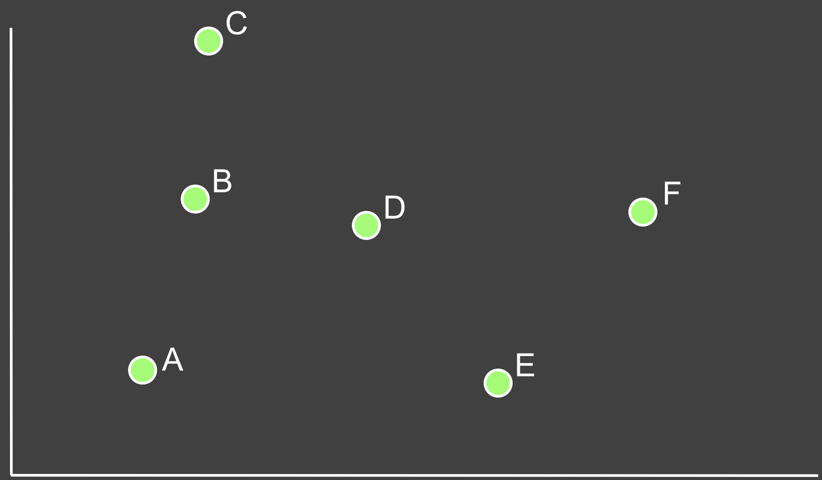






Bivariate data

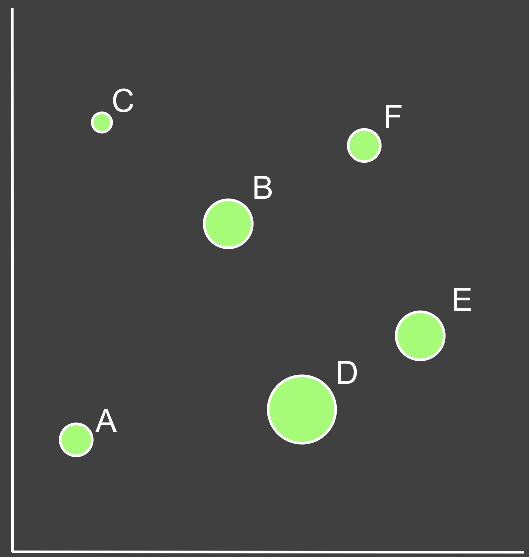
	A	B	C	
1				
2				



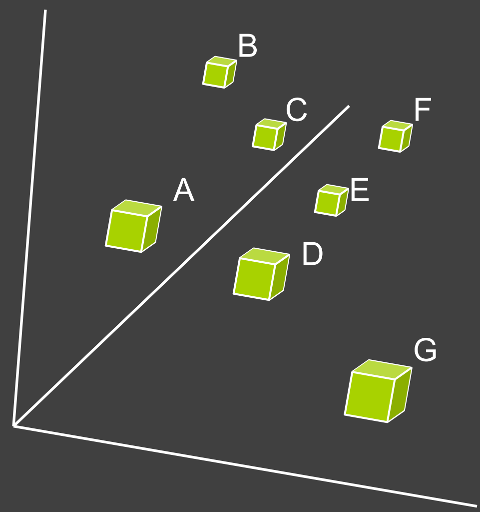
Scatter plot is common

Trivariate data

	A	B	C	
1				
2				
3				



3D scatter plot is possible



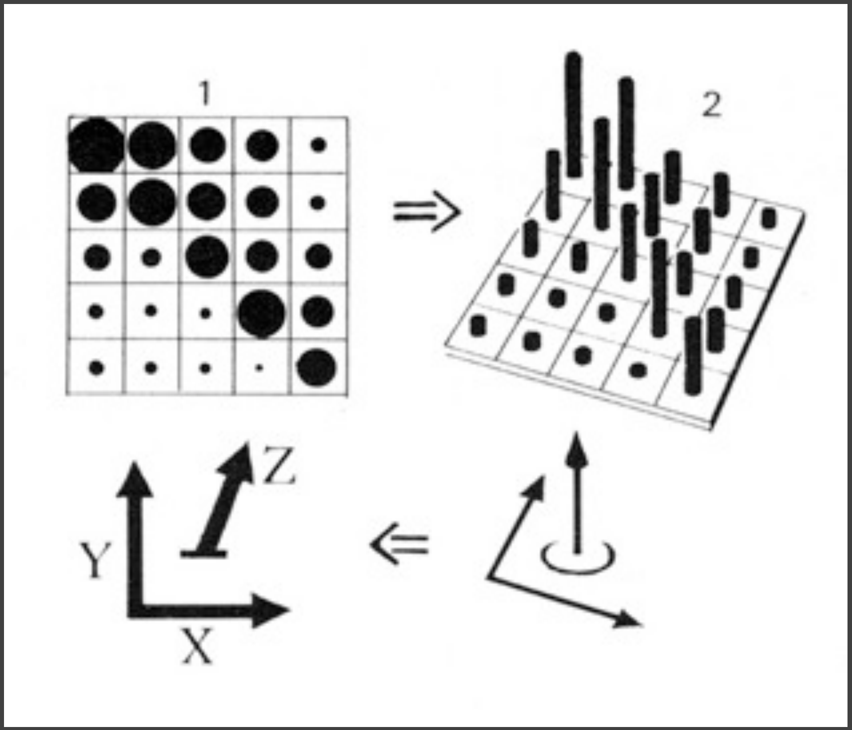
Three variables

Two variables [x,y] can map to points

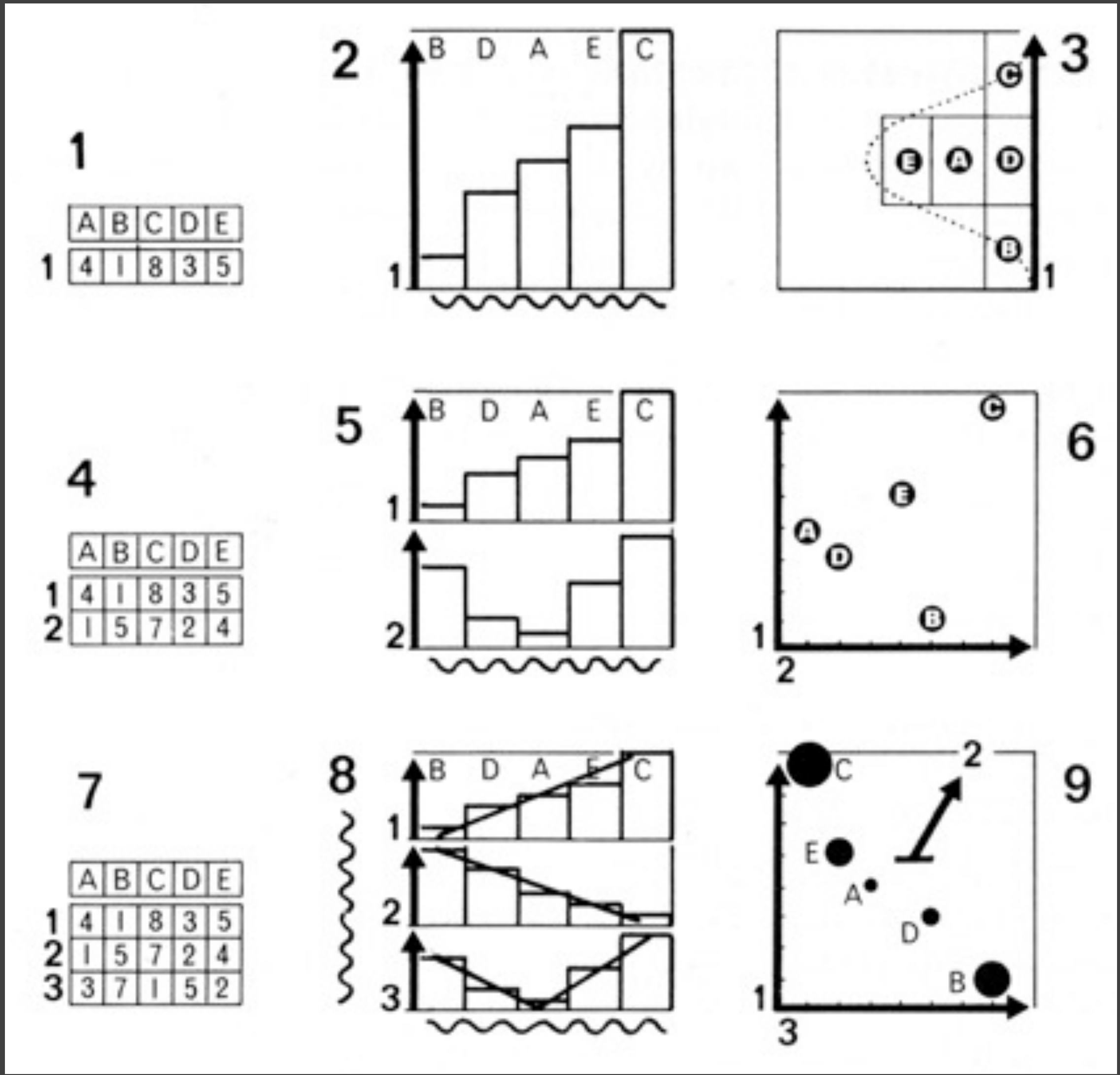
- Scatterplots, maps, ...

Third variable [z] must use

- Color, size, shape, ...



Large design space (visual metaphors)



[Bertin, Graphics and Graphic Info. Processing, 1981]

Multidimensional data

How many variables can be depicted in an image?

	A	B	C	
1				
2				
3				
4				
5				
6				
7				
8				

Multidimensional data

How many variables can be depicted in an image?

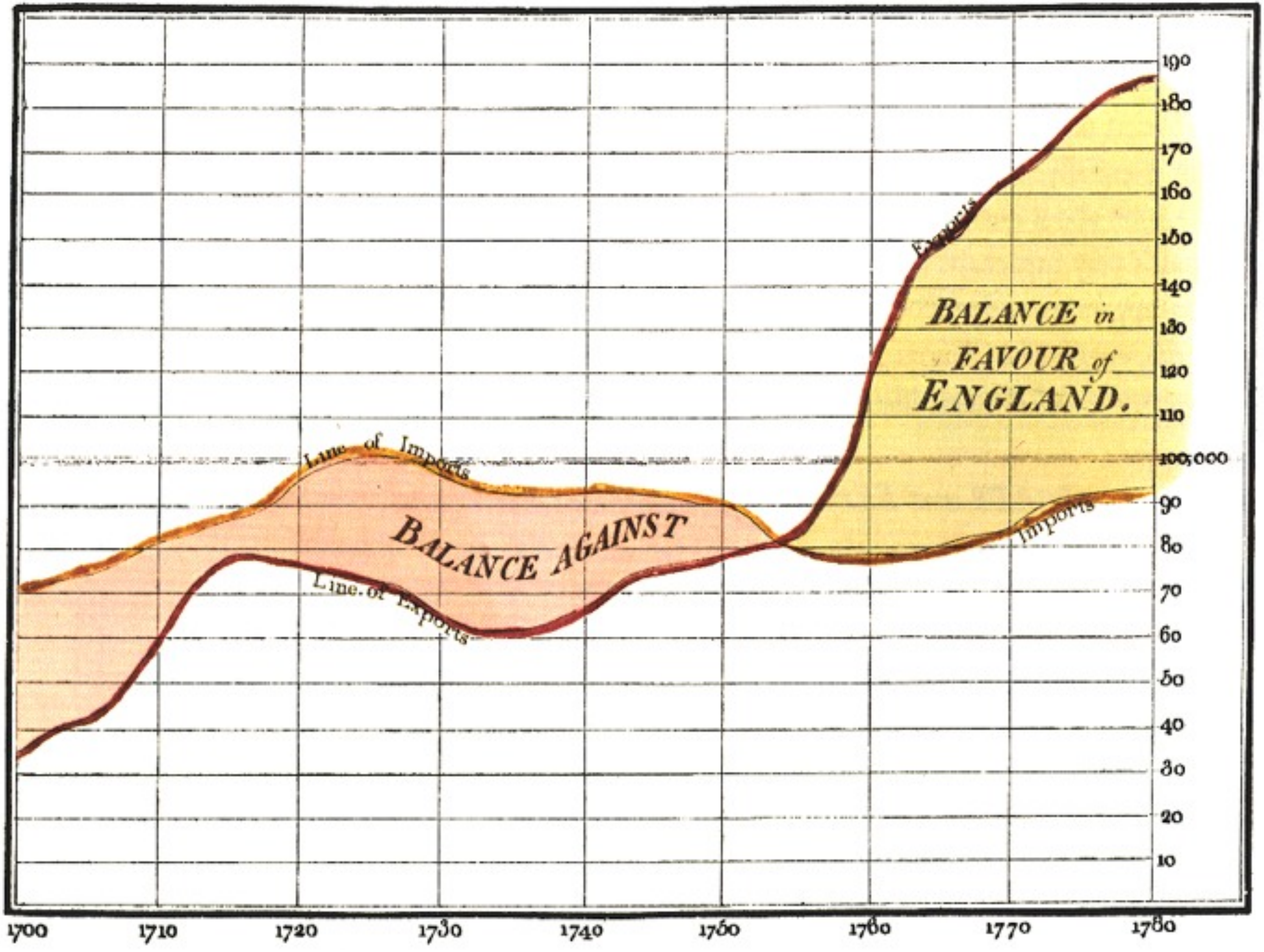
	A	B	C	
1				
2				
3				
4				
5				
6				
7				
8				

"With up to three rows, a data table can be constructed directly as a single image ... However, an image has only three dimensions. And this barrier is impassible."

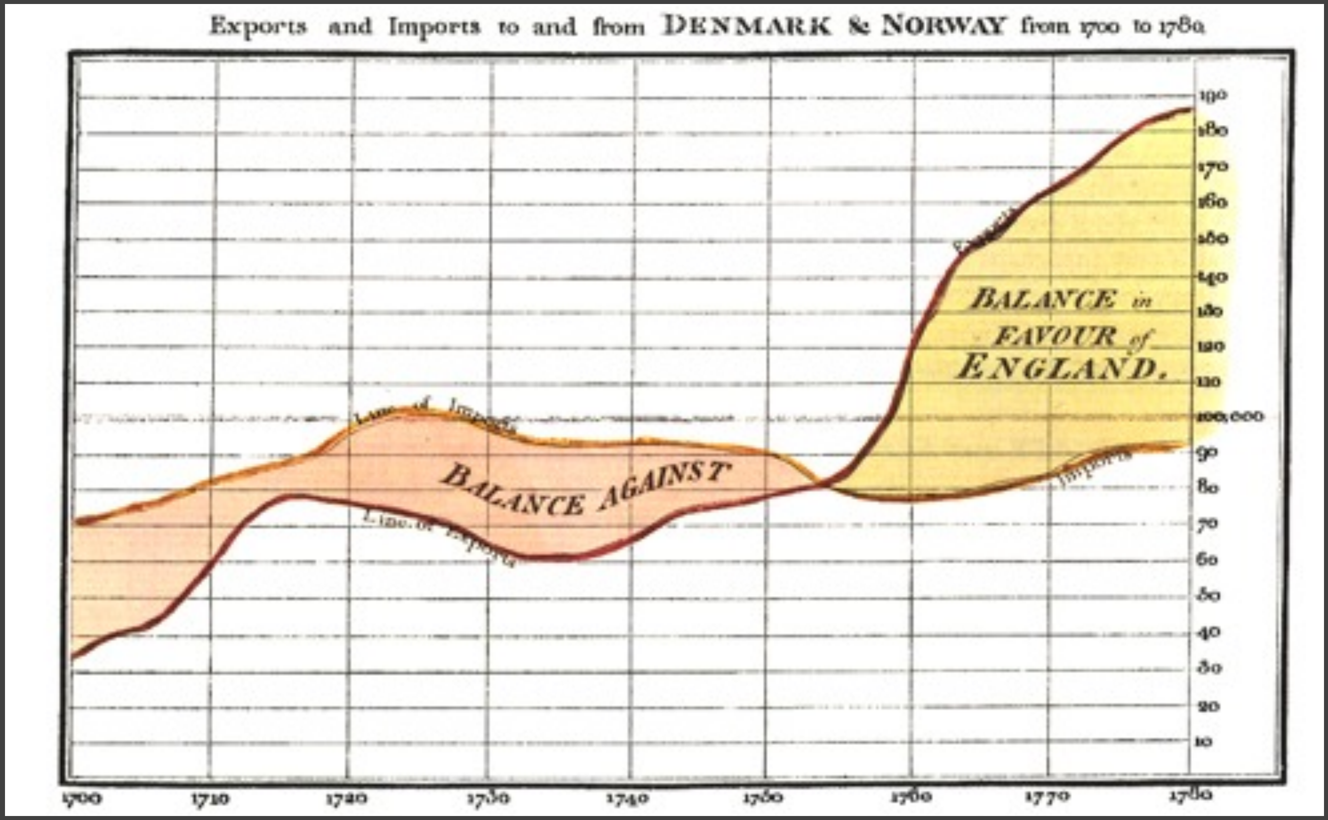
Bertin

Deconstructions

Exports and Imports to and from DENMARK & NORWAY from 1700 to 1780.



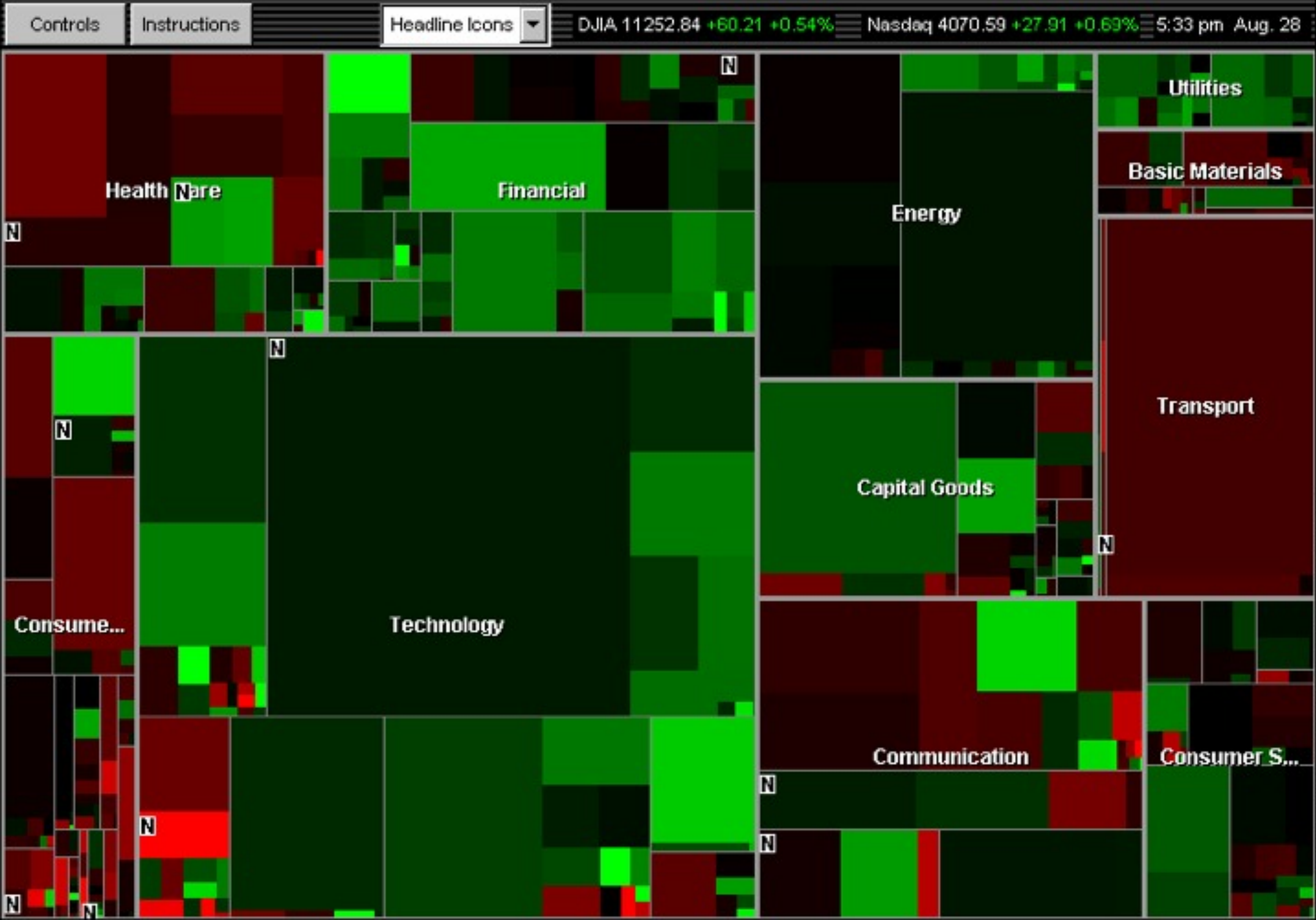
Playfair 1786



x-axis: year (Q)

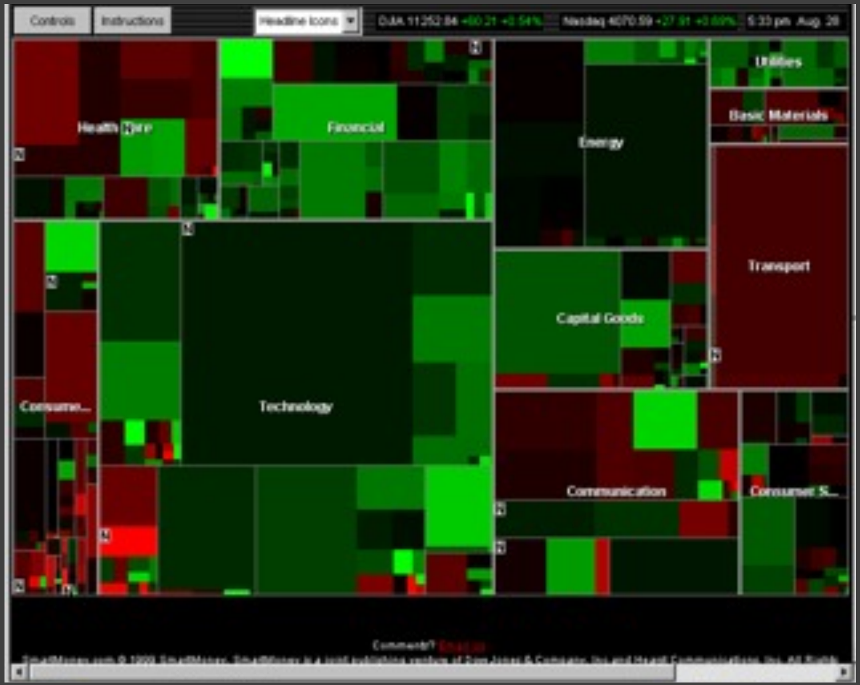
y-axis: currency (Q)

color: imports/exports (N, O)



http://www.smartmoney.com/marketmap/

Wattenberg 1998



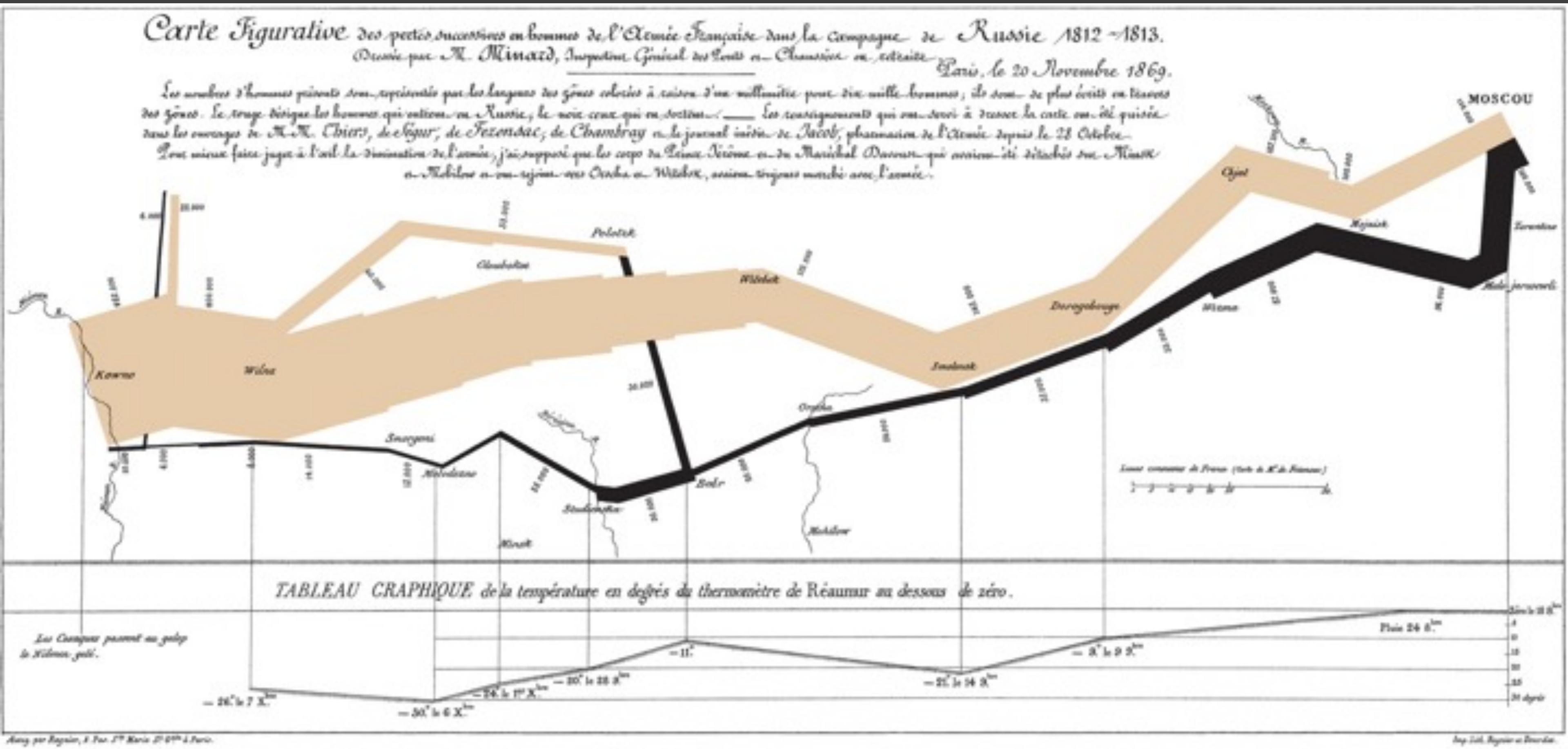
rectangle size: market cap (Q)

rectangle position: market sector (N), market cap (Q)

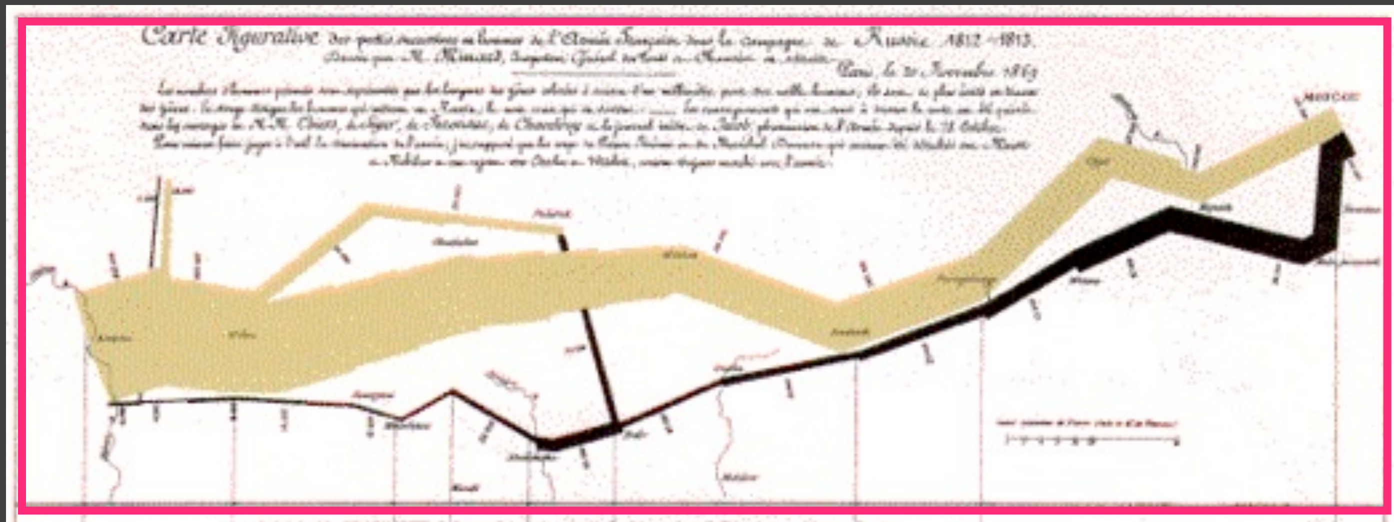
color hue: loss vs. gain (N, O)

color value: magnitude of loss or gain (Q)

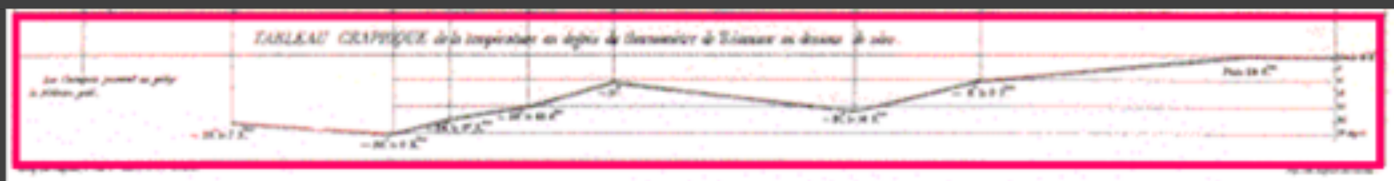
Minard 1869: Napoleon's march



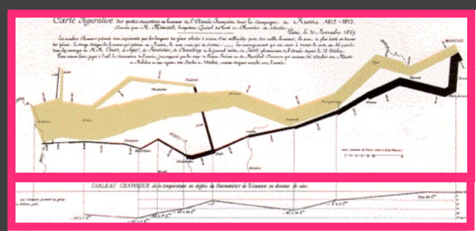
Single axis composition



+



=

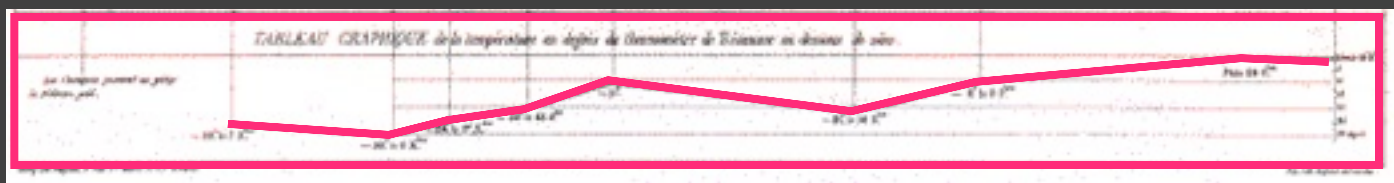


[based on slide from Mackinlay]

Mark composition

y-axis: temperature (Q)

\+ x-axis: longitude (Q) / time (O)

= 

temp over space/time (Q x Q)

[based on slide from Mackinlay]

Mark composition

y-axis: longitude (Q)

\+ x-axis: latitude (Q)

\+ width: army size (Q)

= 

army position (Q x Q) and army size (Q)

[based on slide from Mackinlay]

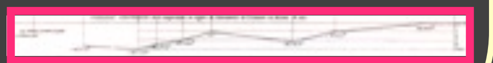
longitude (Q)

latitude (Q)

army size (Q)

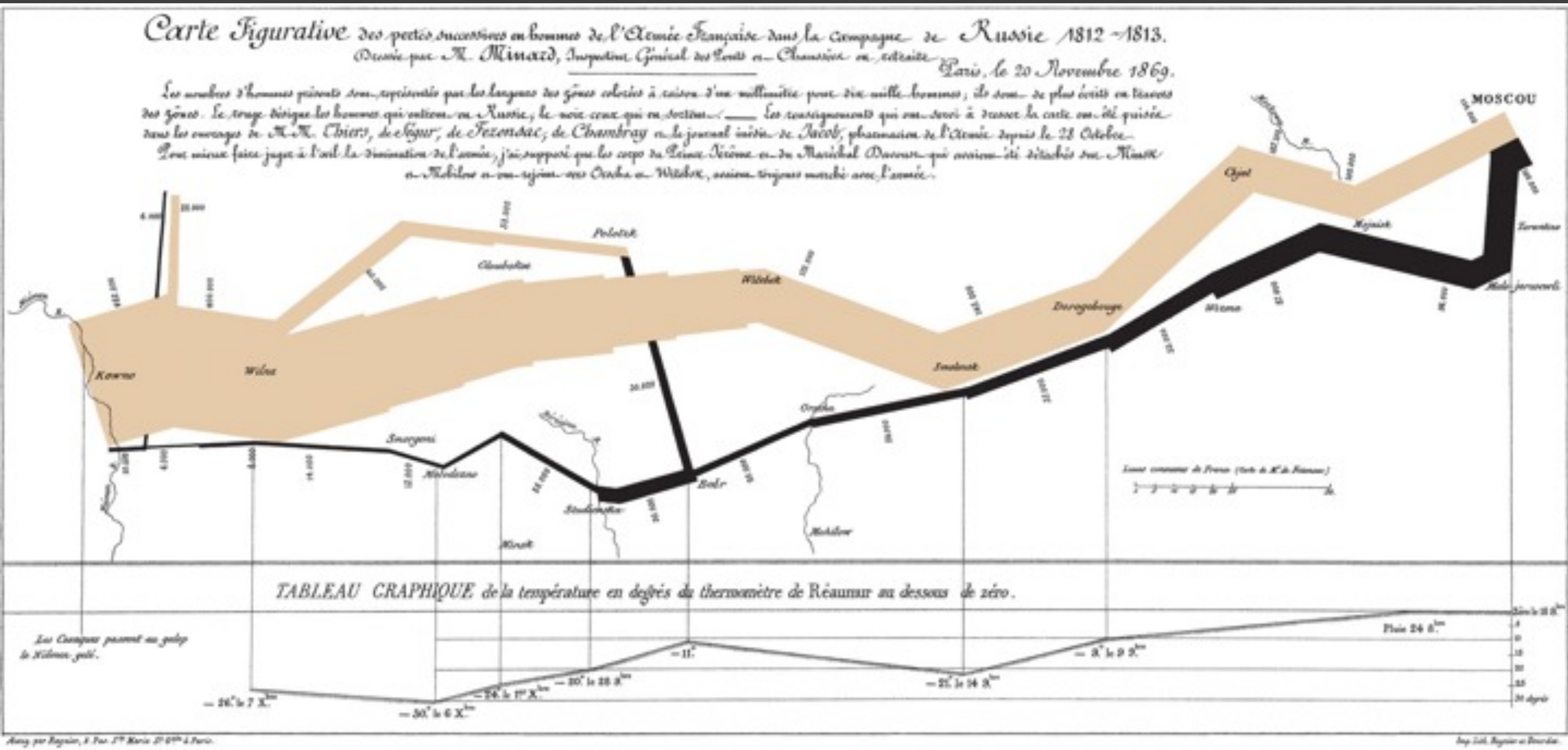
temperature (Q)

latitude (Q) / time (O)



[based on slide from Mackinlay]

Minard 1869: Napoleon’s march



Depicts at least 5 quantitative variables. Any others?

Formalizing Design

(Mackinlay 1986)

Choosing Visual Encodings

Challenge:
Assume 8 visual encodings and *n* data attributes. We would like to pick the "best" encoding among a combinatorial set of possibilities with size $(n+1)^8$

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.

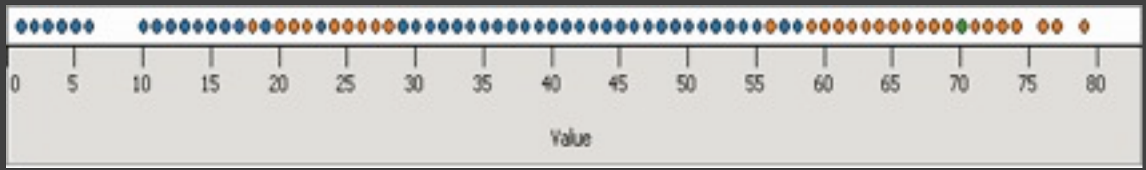
Design Criteria (Mackinlay)

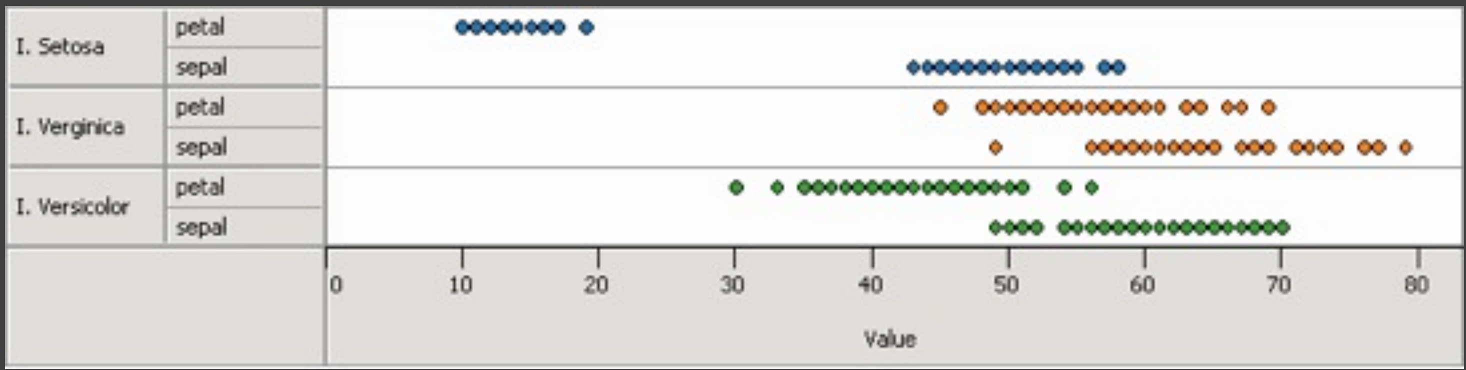
Expressiveness

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.

Cannot express the facts

A one-to-many ($1 \rightarrow N$) relation cannot be expressed in a single horizontal dot plot because multiple tuples are mapped to the same position





Expresses facts not in the data

A length is interpreted as a quantitative value;

∴ Length of bar says something untrue about N data

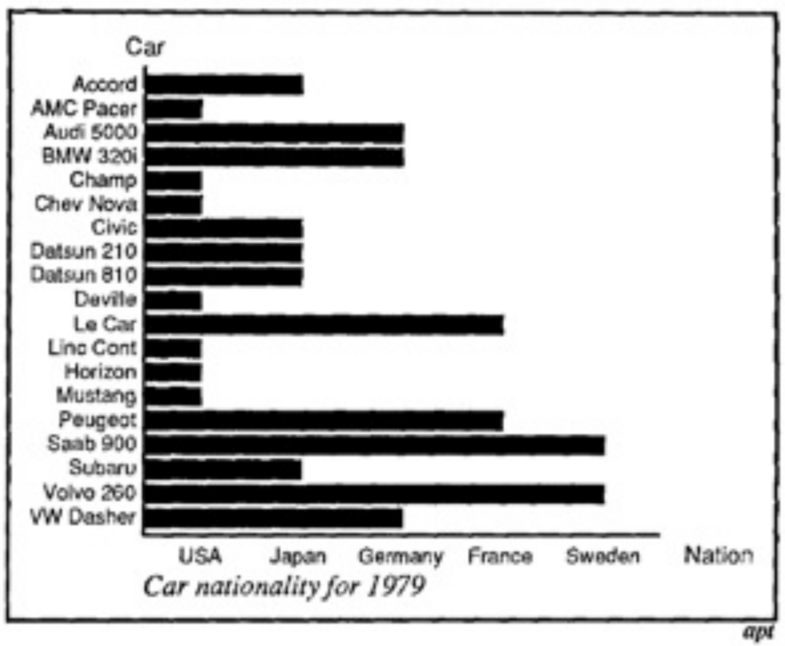


Fig. 11. Incorrect use of a bar chart for the *Nation* relation. The lengths of the bars suggest an ordering on the vertical axis, as if the USA cars were longer or better than the other cars, which is not true for the *Nation* relation.

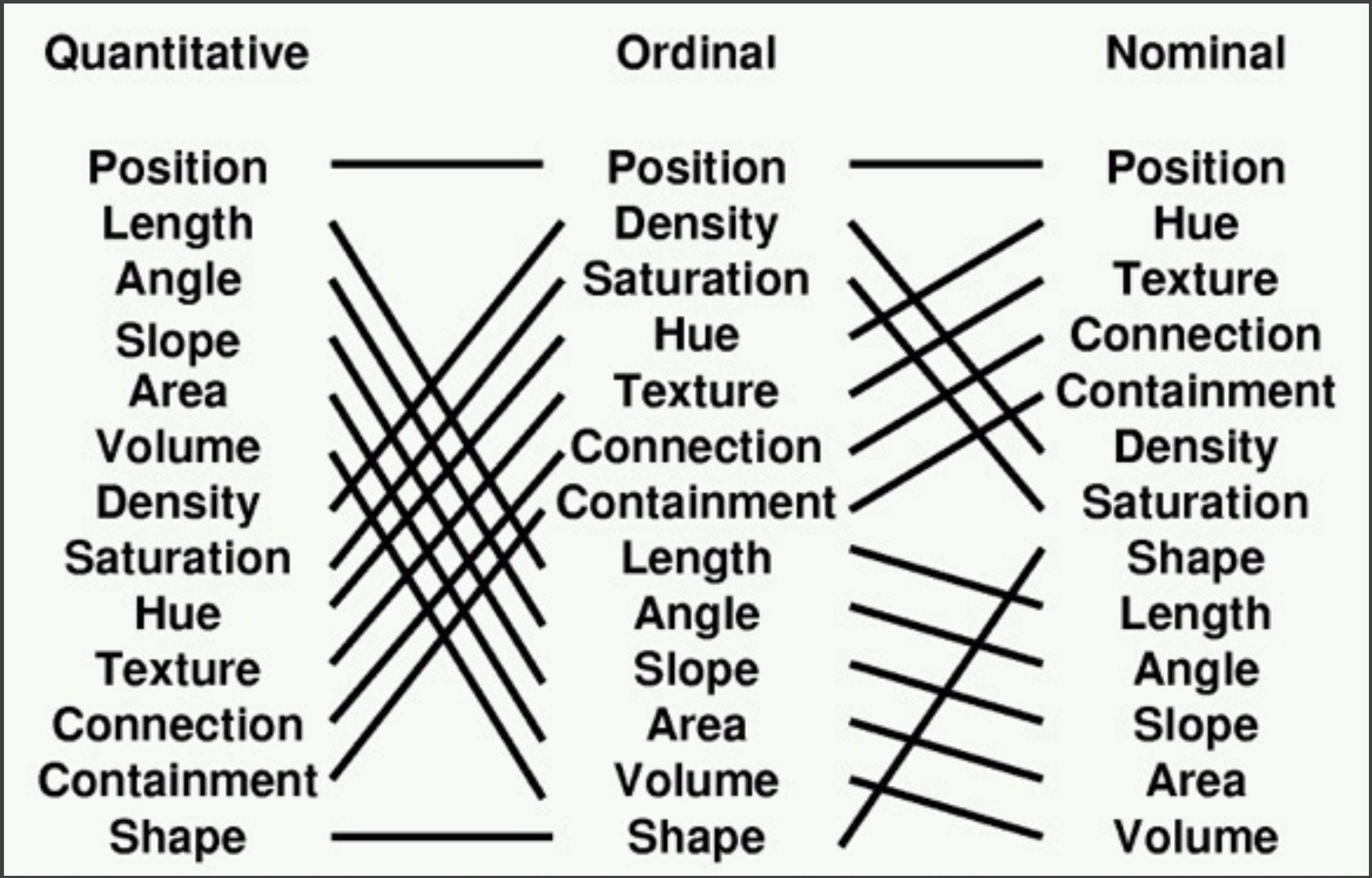
[Mackinlay, APT, 1986]

Design Criteria (Mackinlay)

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's Ranking



Conjectured *effectiveness* of the encoding

Mackinlay's Design Algorithm

User formally specifies data model and type

- Additional input: ordered list of data variables to show

APT searches over design space

- Tests expressiveness of each visual encoding
- Generates specification for encodings that pass test
- Tests perceptual effectiveness of resulting image

Outputs the "most effective" visualization

Limitations

Does not cover many visualization techniques

- Bertin and others discuss networks, maps, diagrams
- Does not consider 3D, animation, illustration, photography, …

Does not model interaction

Does not consider semantic data types / conventions

Summary

Formal specification

- Data model
- Image model
- Encodings mapping data to image

Choose expressive and effective encodings

- Formal test of expressiveness
- Experimental tests of perceptual effectiveness

Assignment 1: Visualization Design

Design a static visualization for a given data set.

Deliverables (submit via Catalyst)

- Image of your visualization
- Short description and design rationale (≤ 4 para.)

Due by ***5:00pm*** on **Monday 1/13**.