Data Visualization

Steve Marschner
Cornell CS 3220

unless noted, images are from
Tufte, *The Visual Display of Quantitative Information*
(these slides also indebted to Pat Hanrahan's slides for CS448B at Stanford)

Data

A lot of 3220 is about data

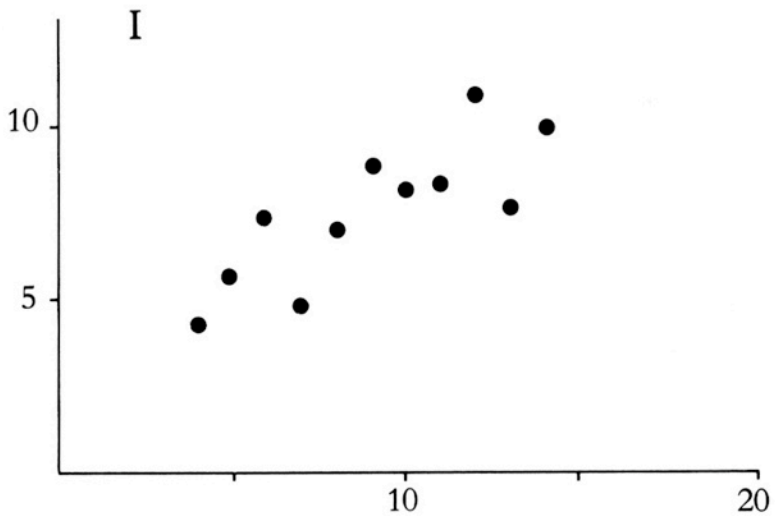
- input to fitting problems
- output of simulations

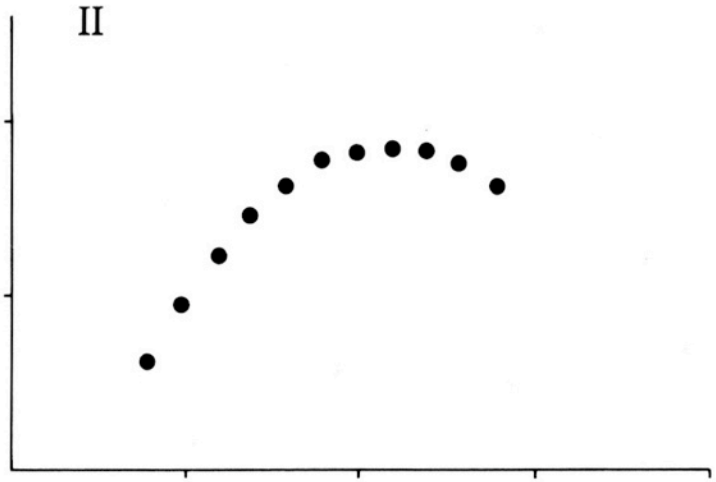
Understanding all but the simplest is not easy

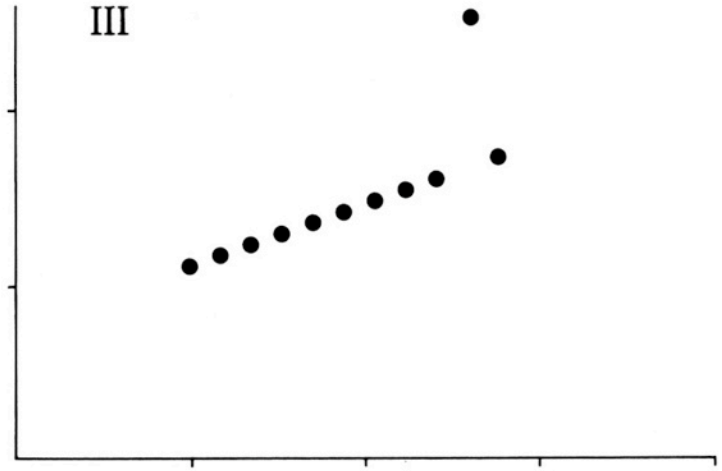
- tables of numbers give little insight
- appropriate pictures are invaluable!

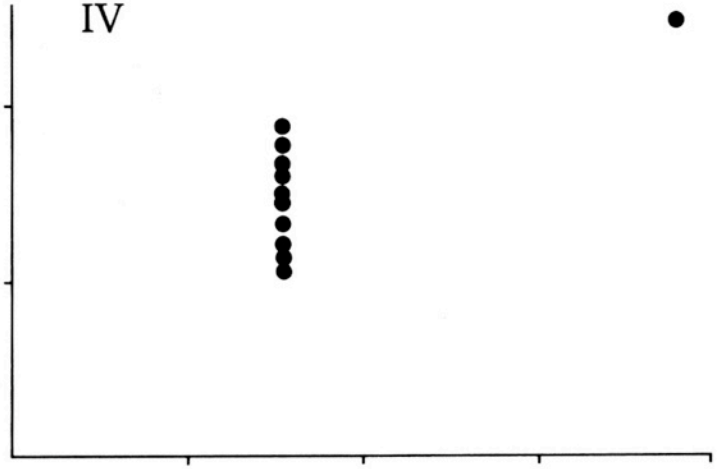
I		II		III		IV	
X	Y	X	Y	X	Y	X	Y
10.0	8.04	10.0	9.14	10.0	7.46	8.0	6.58
8.0	6.95	8.0	8.14	8.0	6.77	8.0	5.76
13.0	7.58	13.0	8.74	13.0	12.74	8.0	7.71
9.0	8.81	9.0	8.77	9.0	7.11	8.0	8.84
11.0	8.33	11.0	9.26	11.0	7.81	8.0	8.47
14.0	9.96	14.0	8.10	14.0	8.84	8.0	7.04
6.0	7.24	6.0	6.13	6.0	6.08	8.0	5.25
4.0	4.26	4.0	3.10	4.0	5.39	19.0	12.50
12.0	10.84	12.0	9.13	12.0	8.15	8.0	5.56
7.0	4.82	7.0	7.26	7.0	6.42	8.0	7.91
5.0	5.68	5.0	4.74	5.0	5.73	8.0	6.89

$N = 11$
mean of X's $= 9.0$
mean of Y's $= 7.5$
equation of regression line: $Y = 3 + 0.5X$
standard error of estimate of slope $= 0.118$
$t = 4.24$
sum of squares $X - \overline{X} = 110.0$
regression sum of squares $= 27.50$
residual sum of squares of $Y = 13.75$
correlation coefficient $= .82$
$r^2 = .67$


I
10
5
10
20


II


III


IV

Purposes of visualization

Organize and display data (for yourself)

provide data in a form our brains & visual systems are able to use

making pictures of data helps you understand it

designing visualizations forces you to organize the data

a key part of the intellectual and creative process

Present data (for others)

data in support of arguments (scientific, policy, …)

data for making decisions (funding, operational, …)

good presentation of data is key to any good presentation of complex technical material

a part of informative & persuasive communication

John C. Snow (1854)

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[NASA]

Space Shuttle mission STS-51-L, about 75 sec. after liftoff. 1986

HISTORY OF O-RING DAMAGE ON SRM FIELD JOINTS

	SRM No.	Cross Sectional View: Erosion Depth (in.)	Cross Sectional View: Perimeter Affected (deg)	Cross Sectional View: Nominal Dia. (in.)	Top View: Length Of Max Erosion (in.)	Top View: Total Heat Affected Length (in.)	Clocking Location (deg)
61A LH Center Field**	22A	None	None	0.280	None	None	36° --66°
61A LH ~~CENTER~~ FIELD**	22A	NONE	NONE	0.280	NONE	NONE	338°-18°
51C LH Forward Field**	15A	0.010	154.0	0.280	4.25	5.25	163
51C RH Center Field (prim)***	15B	0.038	130.0	0.280	12.50	58.75	354
51C RH Center Field (sec)***	15B	None	45.0	0.280	None	29.50	354
41D RH Forward Field	13B	0.028	110.0	0.280	3.00	None	275
41C LH Aft Field*	11A	None	None	0.280	None	None	--
41B LH Forward Field	10A	0.040	217.0	0.280	3.00	14.50	351
STS-2 RH Aft Field	2B	0.053	116.0	0.280	--	--	90

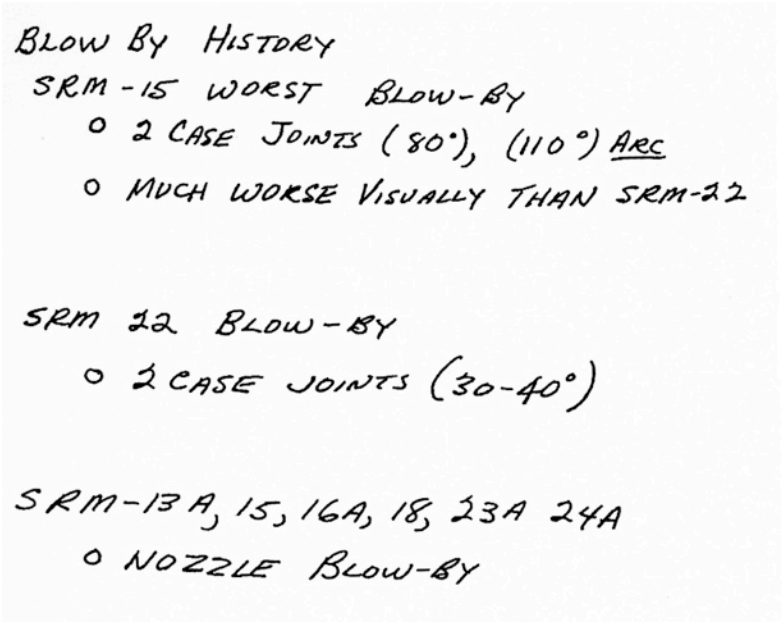
*Hot gas path detected in putty. Indication of heat on O-ring, but no damage.
**Soot behind primary O-ring.
***Soot behind primary O-ring, heat affected secondary O-ring.

Clocking location of leak check port - 0 deg.

OTHER SRM-15 FIELD JOINTS HAD NO BLOWHOLES IN PUTTY AND NO SOOT NEAR OR BEYOND THE PRIMARY O-RING.

SRM-22 FORWARD FIELD JOINT HAD PUTTY PATH TO PRIMARY O-RING, BUT NO O-RING EROSION AND NO SOOT BLOWBY. OTHER SRM-22 FIELD JOINTS HAD NO BLOWHOLES IN PUTTY.

data presented by rocket's manufacturer to argue for canceling the launch.



Blow By History

SRM-15 worst Blow-By

- 2 case joints (80°), (110°) arc
- much worse visually than SRM-22

SRM 22 Blow-By

- 2 case joints (30-40°)

SRM-13A, 15, 16A, 18, 23A 24A

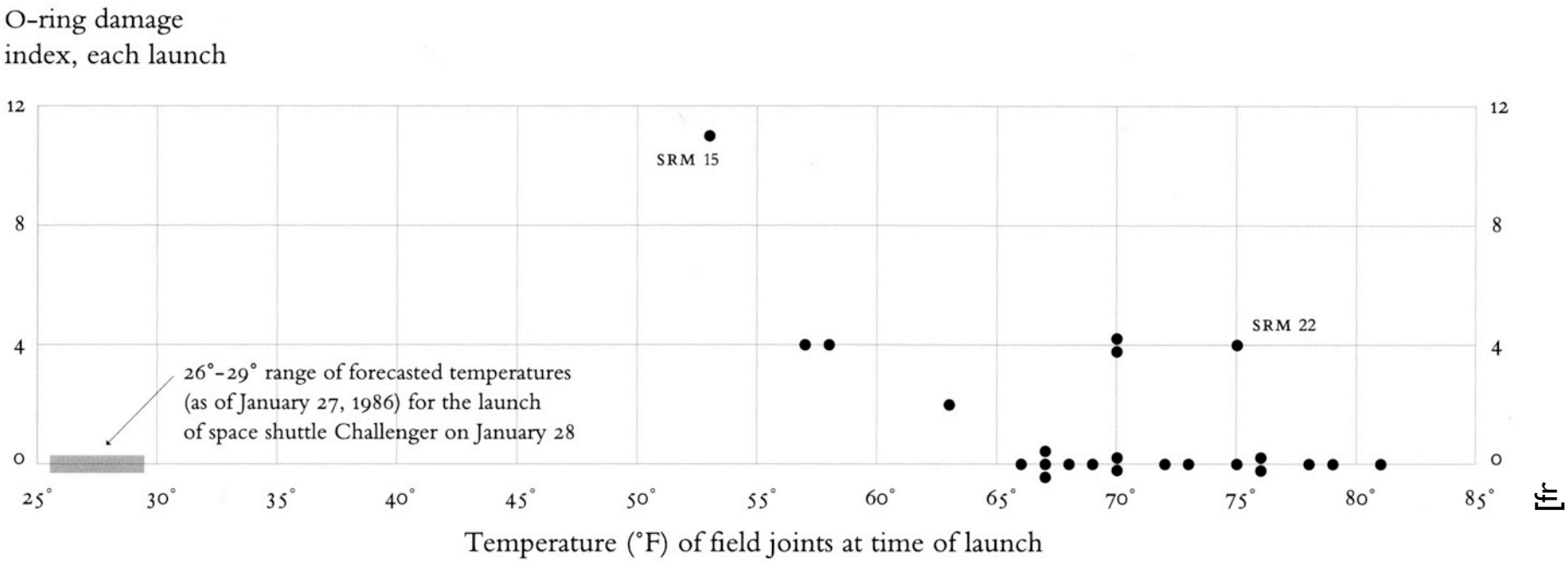
- nozzle Blow-By

History of O-ring Temperatures (degrees-F)

Motor	MBT	Amb	O-ring	Wind
DM-1	68	36	47	10 mph
DM-2	76	45	52	10 mph
QM-3	72.5	40	48	10 mph
QM-4	76	48	51	10 mph
SRM-15	52	64	53	10 mph
SRM-22	77	78	75	10 mph
SRM-25	55	26	29 27	10 mph 25 mph

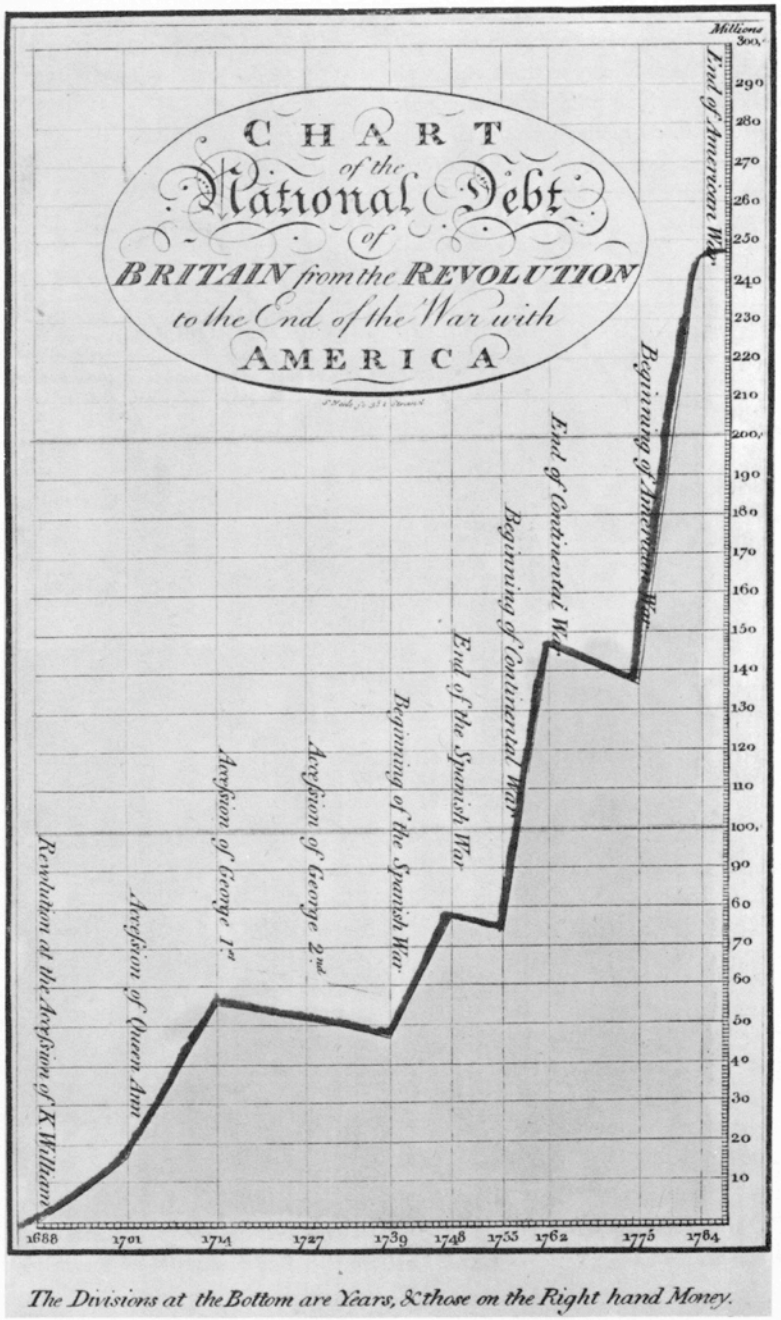
[fr

data presented by rocket's manufacturer to argue for canceling the launch.



Tufte's more convincing re-presentation of the same data. 1997

Graphical integrity



To emphasize growth, use
tall scale and don't adjust for inflation
W. Playfair, 1786

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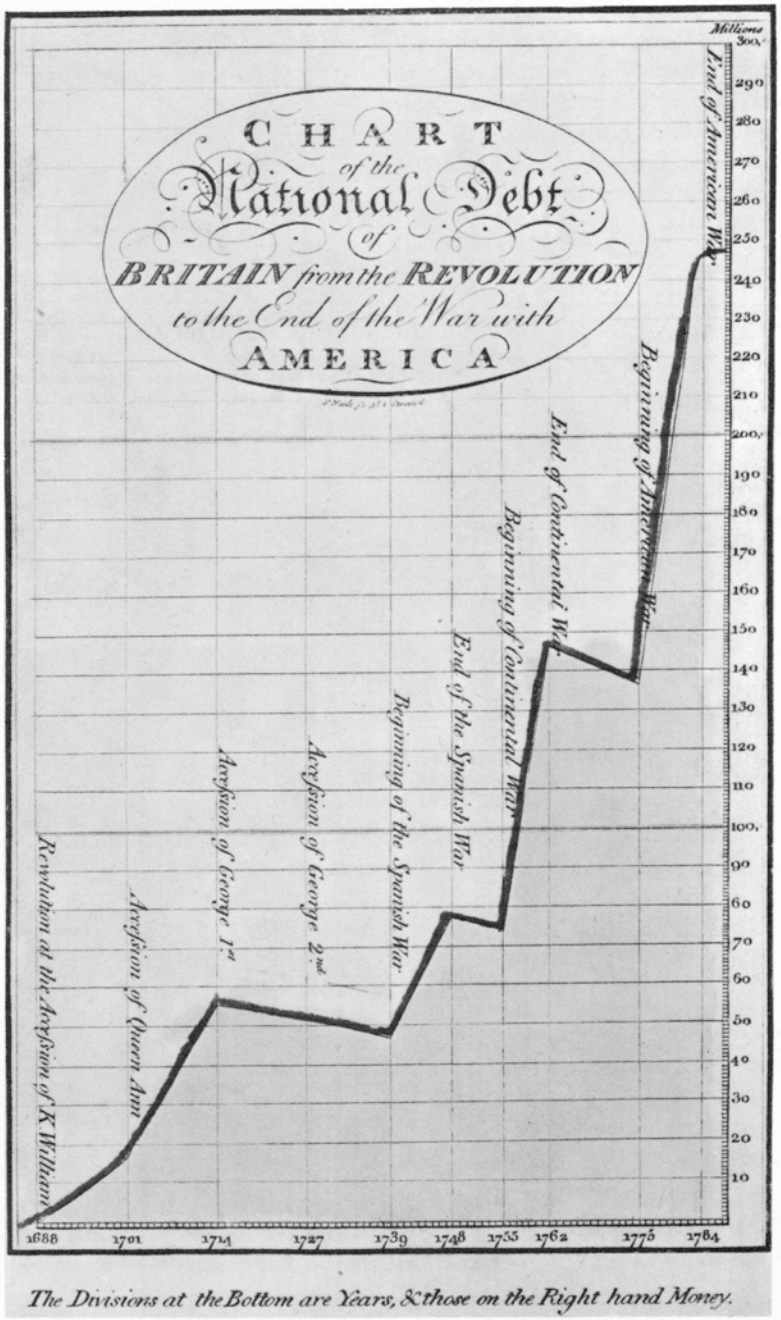
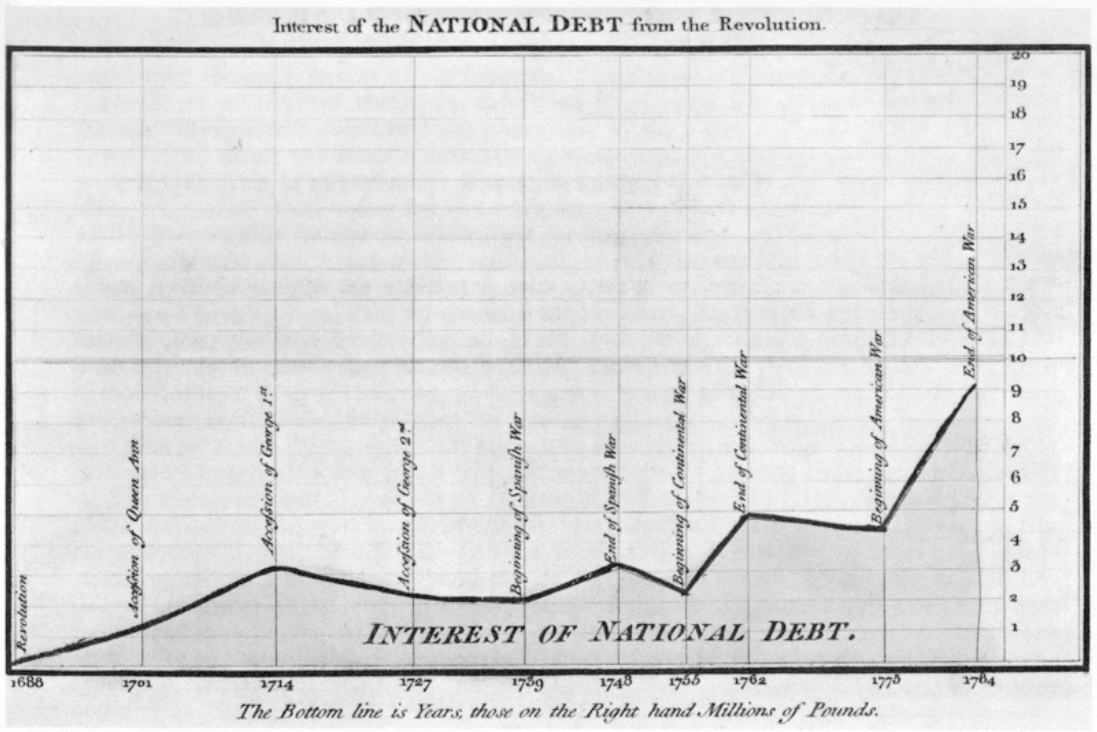
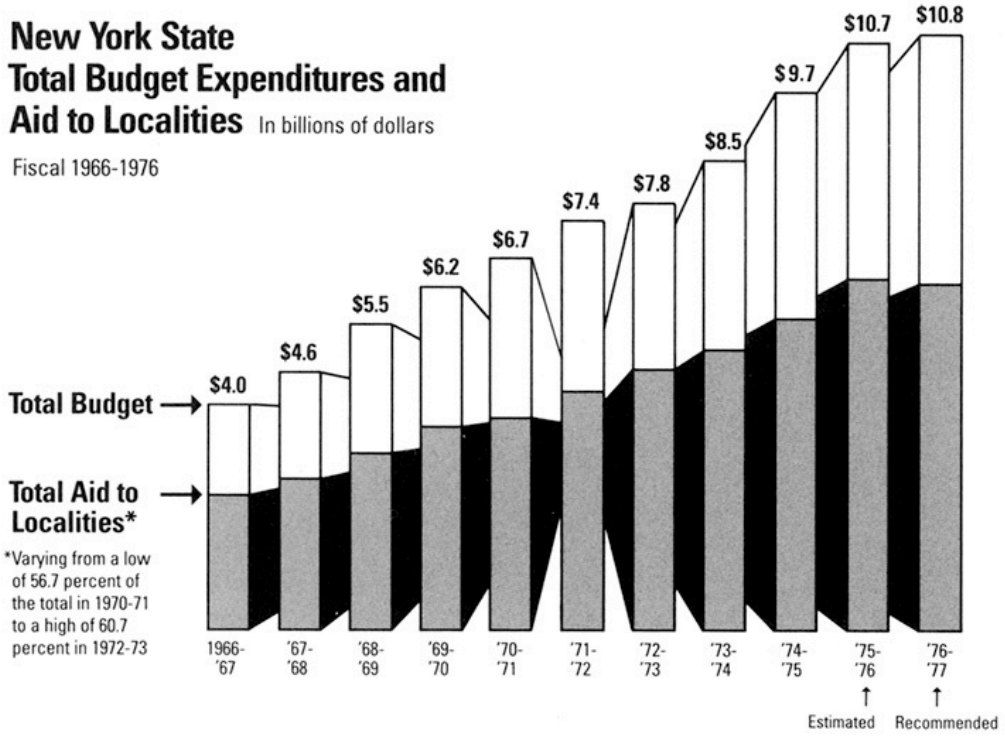
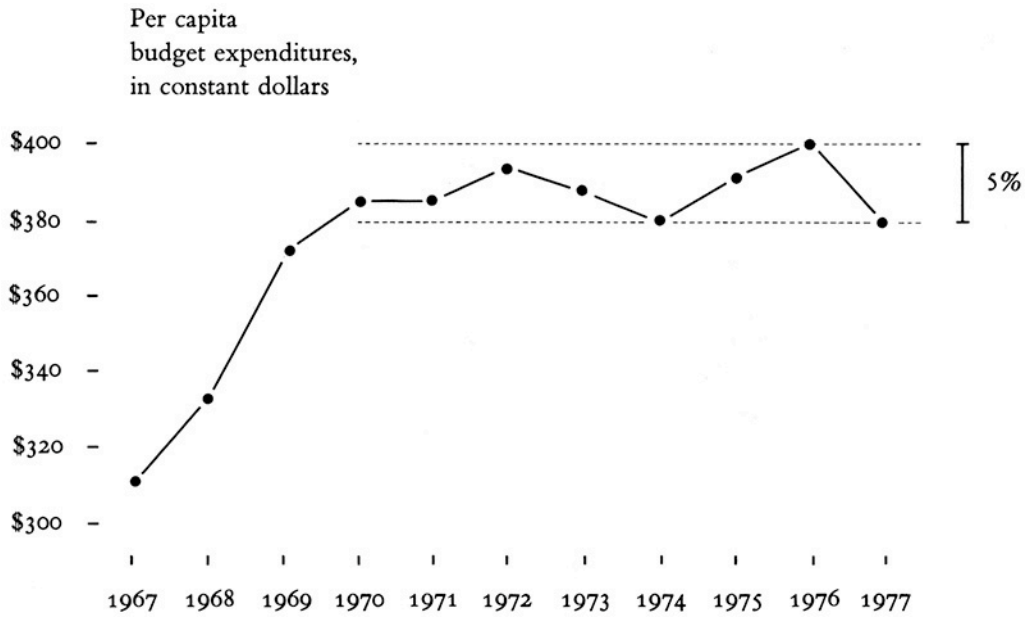


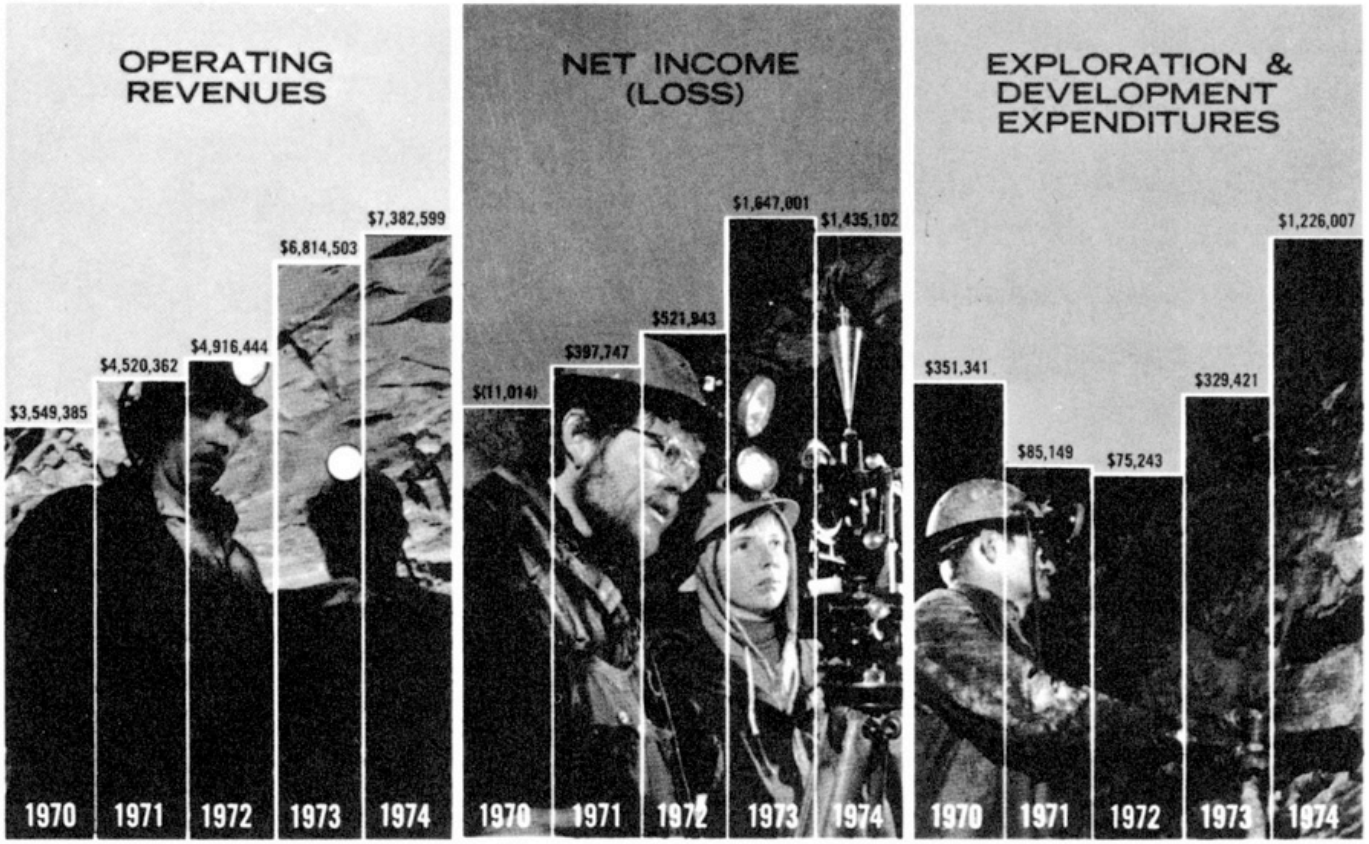




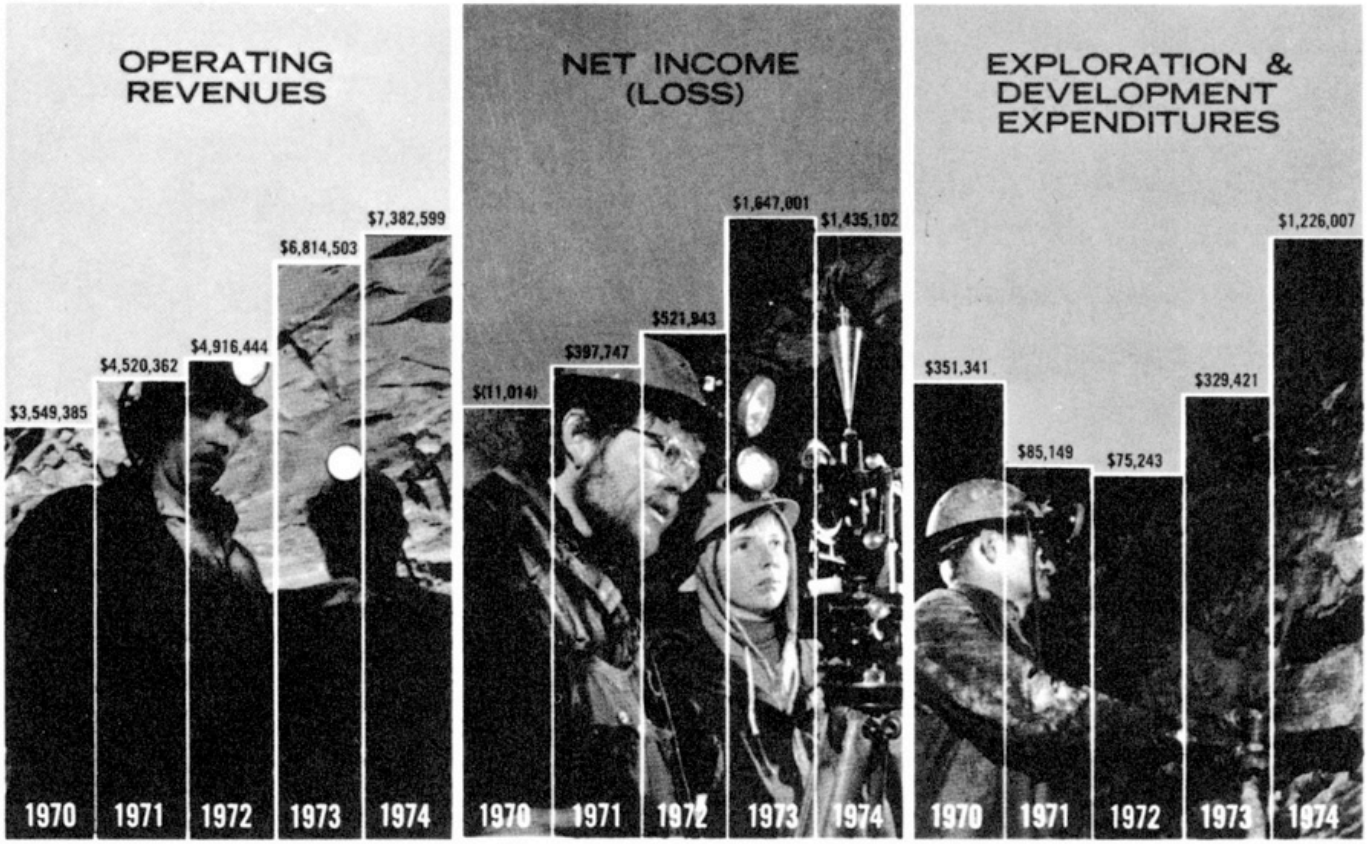
New York Times. 1976



E. R. Tufte. Fair presentation of the same data. 1983



Day Mines, Inc. 1974



Day Mines, Inc. 1974

–$4.2e6

Washington Post, 1978

Mapping data into a visual display

Datatypes

- programming: char, int, float, double, String, …
- scientific data has types too

Graphical information channels

- there are many ways to put the data into pictures
- good datatype-to-channel matches are important!

Datatypes

Nominal select from unorganized set (enumerated type, in C)

apples, oranges, tomatoes, …

Toyota, Ford, Subaru, …

Ordinal ordered set of values (< operator available)

January, February, March, …

Trial 1, Trial 2, Trial 3, …

12 Oak St., 125 Oak St., 129 Oak St., …

S. S. Stevens, *On the theory of scales of measurement* (1946)

Datatypes (quantitative)

Interval values are meaningful, but zero is arbitrary (+, – avail.)

- degrees Celsius
- position
- potential energy

Ratio values are meaningful, meaningful zero (×, ÷ avail.)

- degrees Kelvin
- length
- mass

S. S. Stevens, *On the theory of scales of measurement* (1946)

Graphical information channels

Spatial

- length
- position
- size (area, volume?)

Color

- value (lightness, black to white)
- saturation (colorfulness, gray to vivid)
- hue (color)
- texture (fill pattern)

Details

- shape
- orientation

Datatypes and channels

Pay attention to data semantics

Chose channel that carries the semantics well

		N	O	I	R
spatial	length				Y
	position	Y	Y	Y	
	size		Y	~	~
color	value		Y		~
	saturation		Y		
	hue	Y			
detail	texture	Y			
	shape	Y			
	orientation		Y	~	

Common types of visualizations

data maps

time series

relational plots

histograms

bar charts

polar plots

color maps

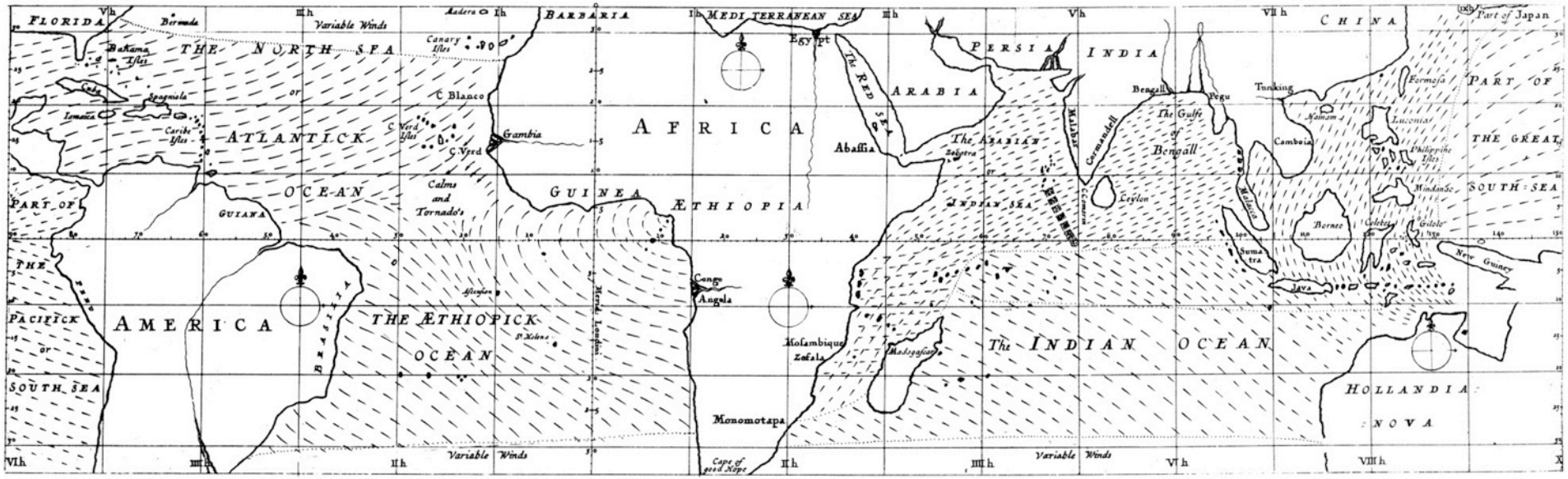
Data Maps

Position: position

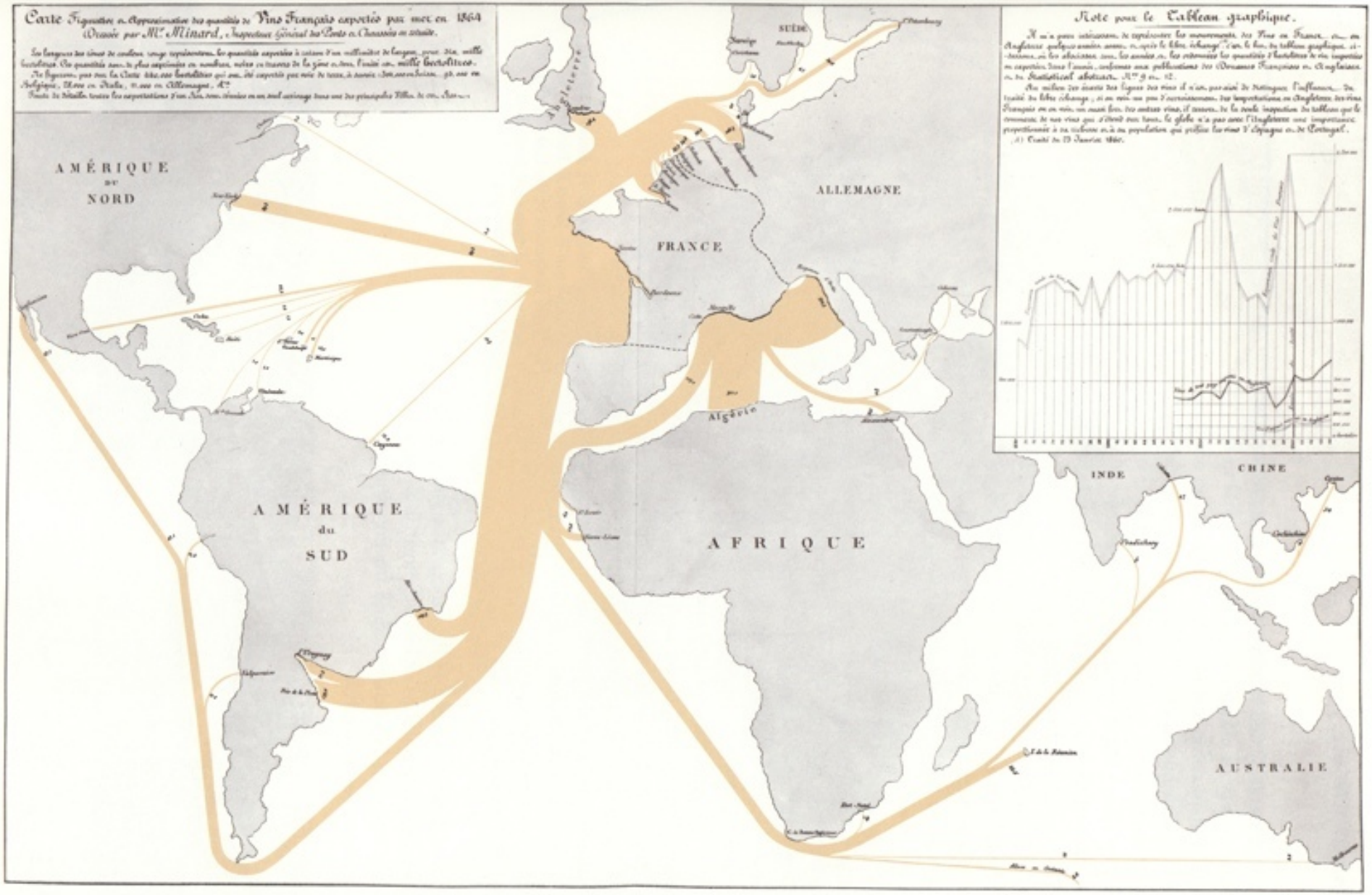
Symbols, colors: various variables (N, O, or Q)

very old form of data visualization

readily interpreted with little training or effort



E. Halley. Map illustrating trade winds. 1686



C. J. Minard. Map illustrating exports of French wine. 1864

Time series

Horizontal axis: time (Interval—Position)

Vertical axis: some quantitative value (often money)

very old form of data visualization

readily interpreted with little training or effort

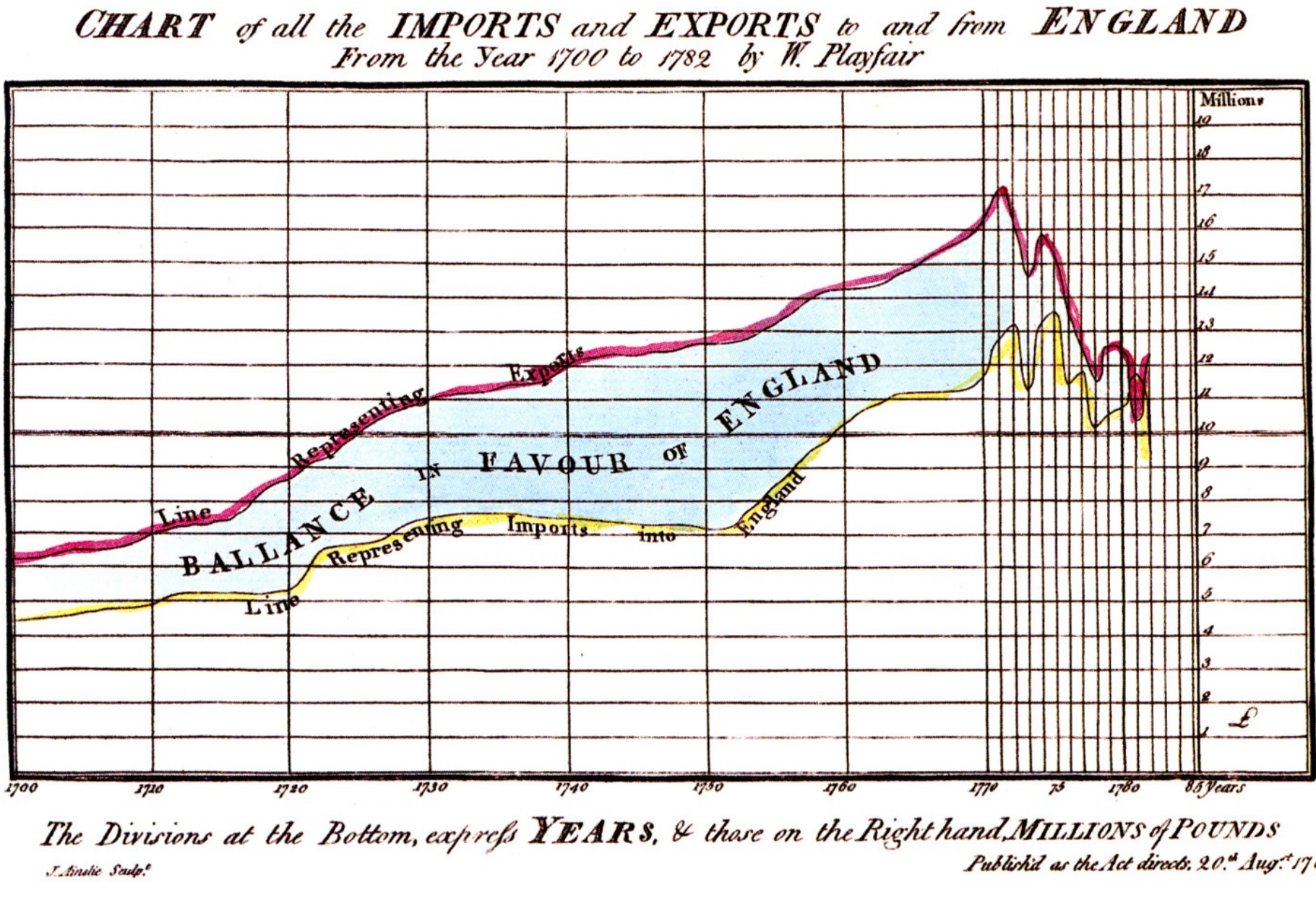
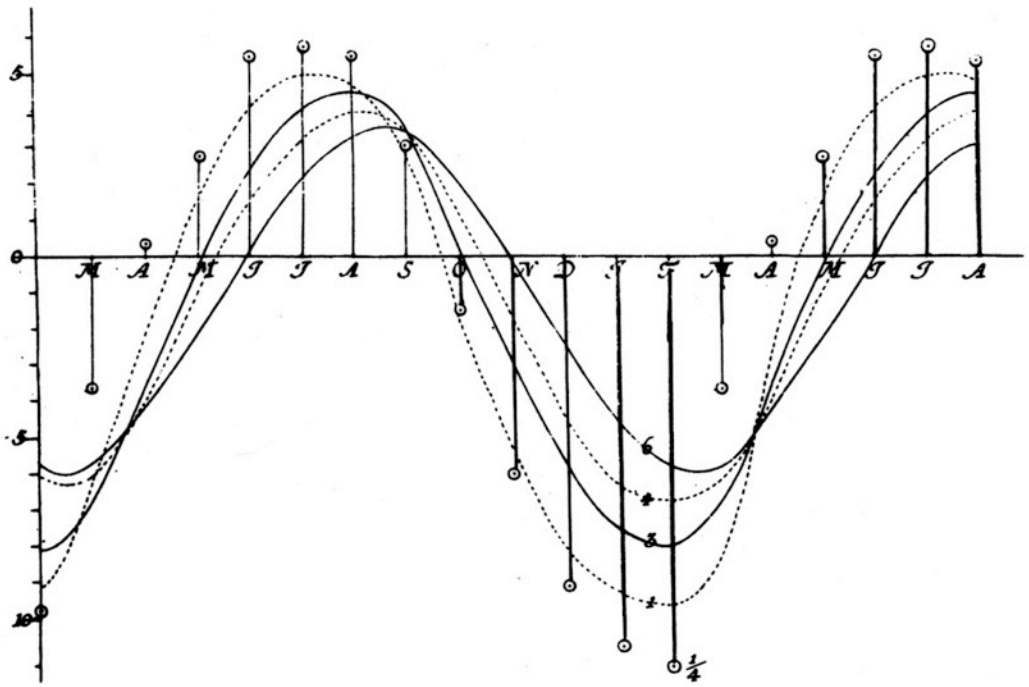
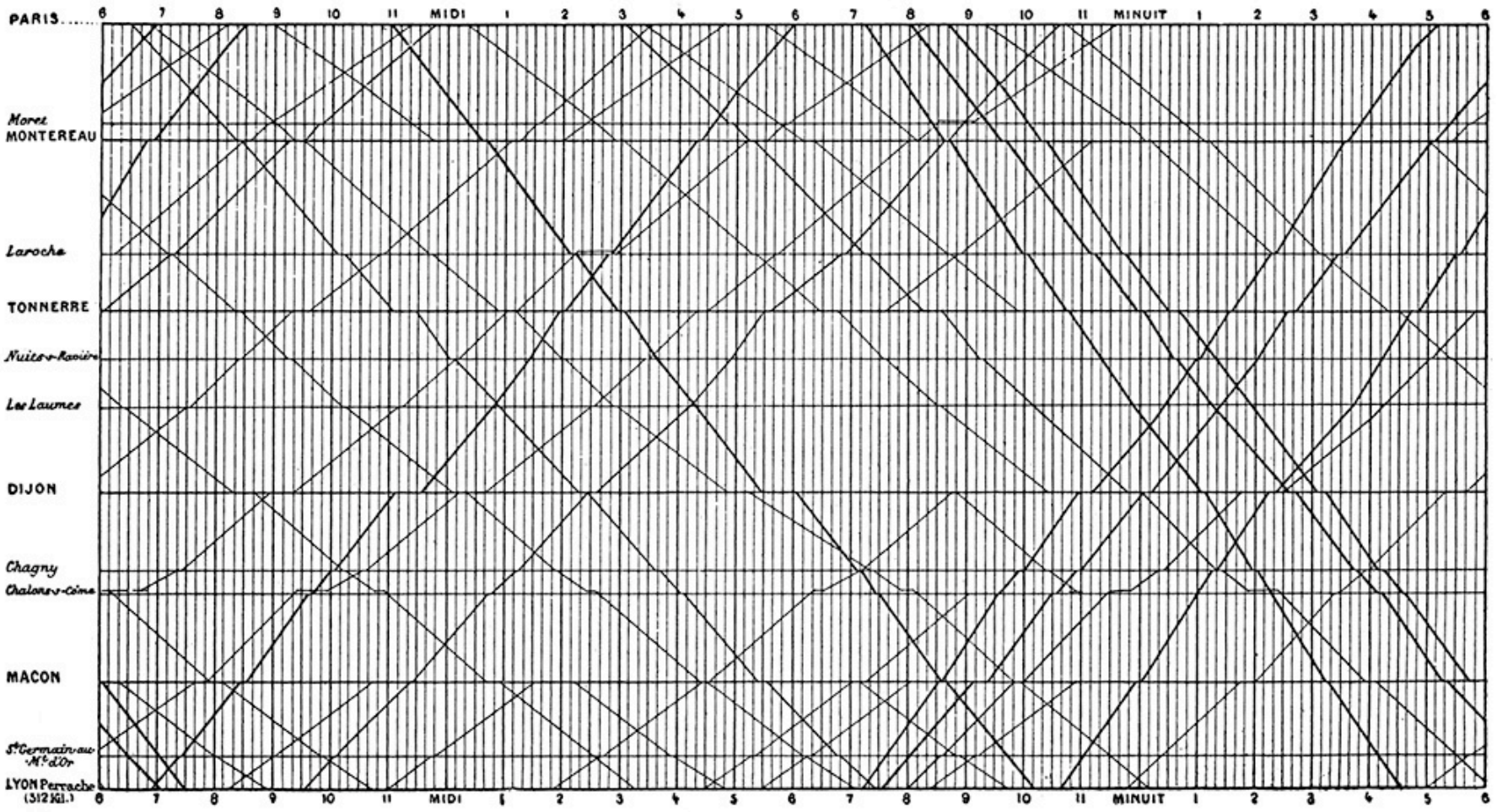


CHART of all the IMPORTS and EXPORTS to and from ENGLAND
From the Year 1700 to 1782 by W. Playfair
Millions
19
18
17
16
15
14
13
12
11
10
9
8
7
6
5
4
3
2
1
£
Line Representing Exports
BALLANCE IN FAVOUR OF ENGLAND
Line Representing Imports into England
1700
1710
1720
1730
1740
1750
1760
1770
75
1780
85 Years
The Divisions at the Bottom, express YEARS, & those on the Right hand, MILLIONS of POUNDS
J. Ainslie Sculp.t
Publish'd as the Act directs. 20.th Aug.t 1785



J.H. Lambert. Soil temperature over time at various depths. 1779



E.J. Marey. Train schedule for Paris–Lyon line. 1885

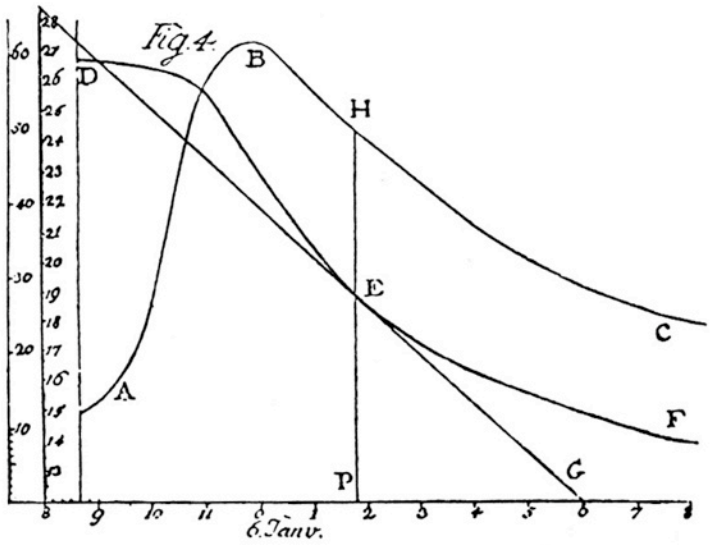
Relational plots

Horizontal axis: alleged "cause"

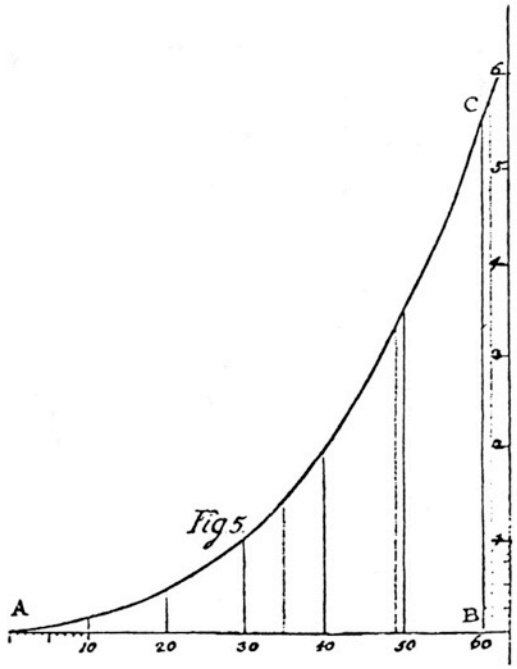
Vertical axis: alleged "effect"

very powerful tool to investigate relationships

scatter plot for unordered set of points;
connected line for ordered sequence of points
or to emphasize functional "law"

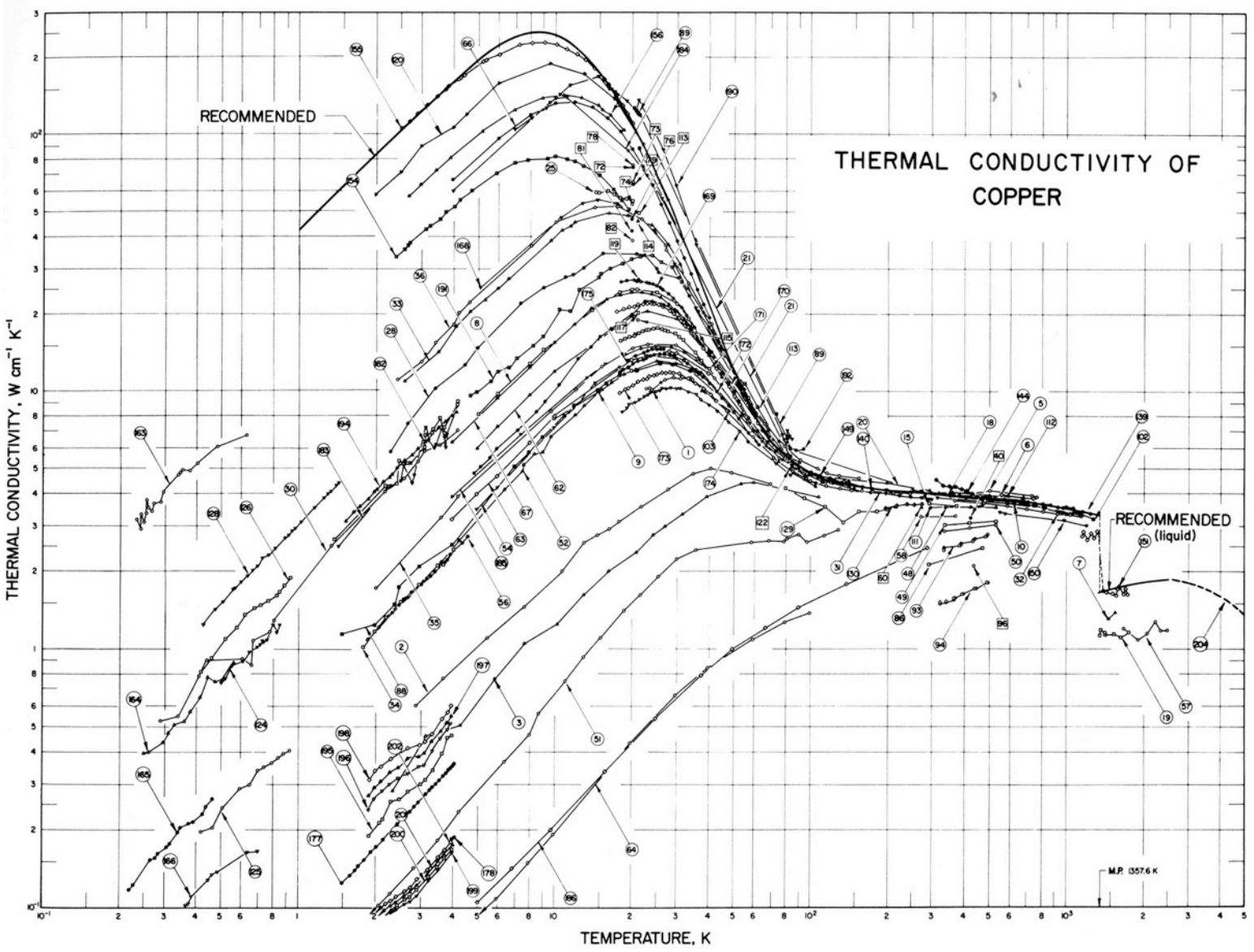


ABC: temperature over time
DEF: height of water over time

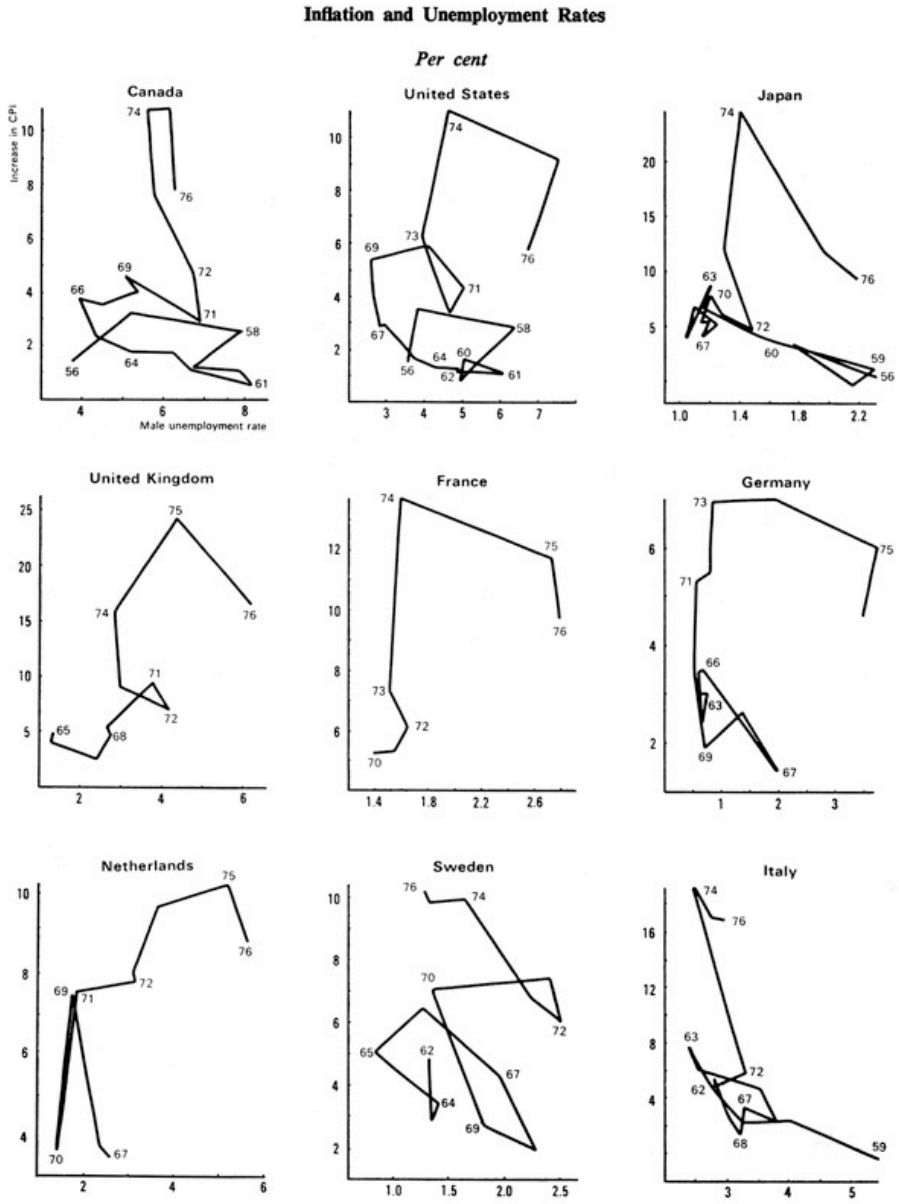


evaporation rate
vs. temperature

J.H. Lambert: influence of temperature on evaporation. 1769



C.Y. Ho et al. Review of thermal conductivity data. 1974



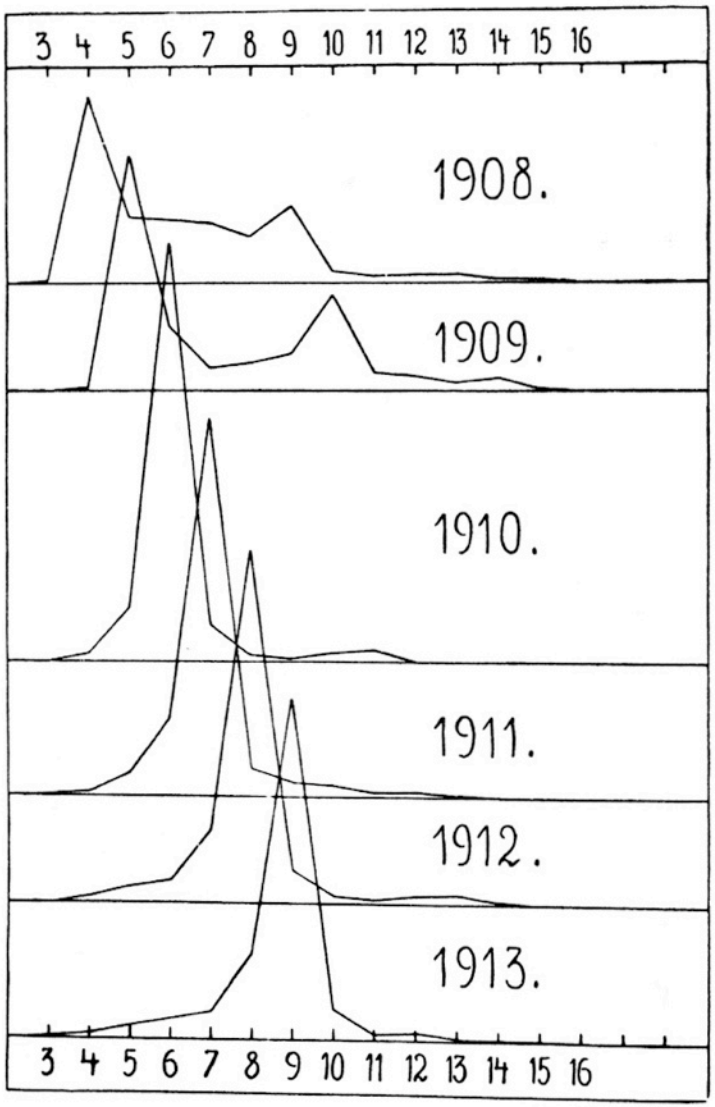
P. McCracken et al. Phillips curves. 1977

Histograms

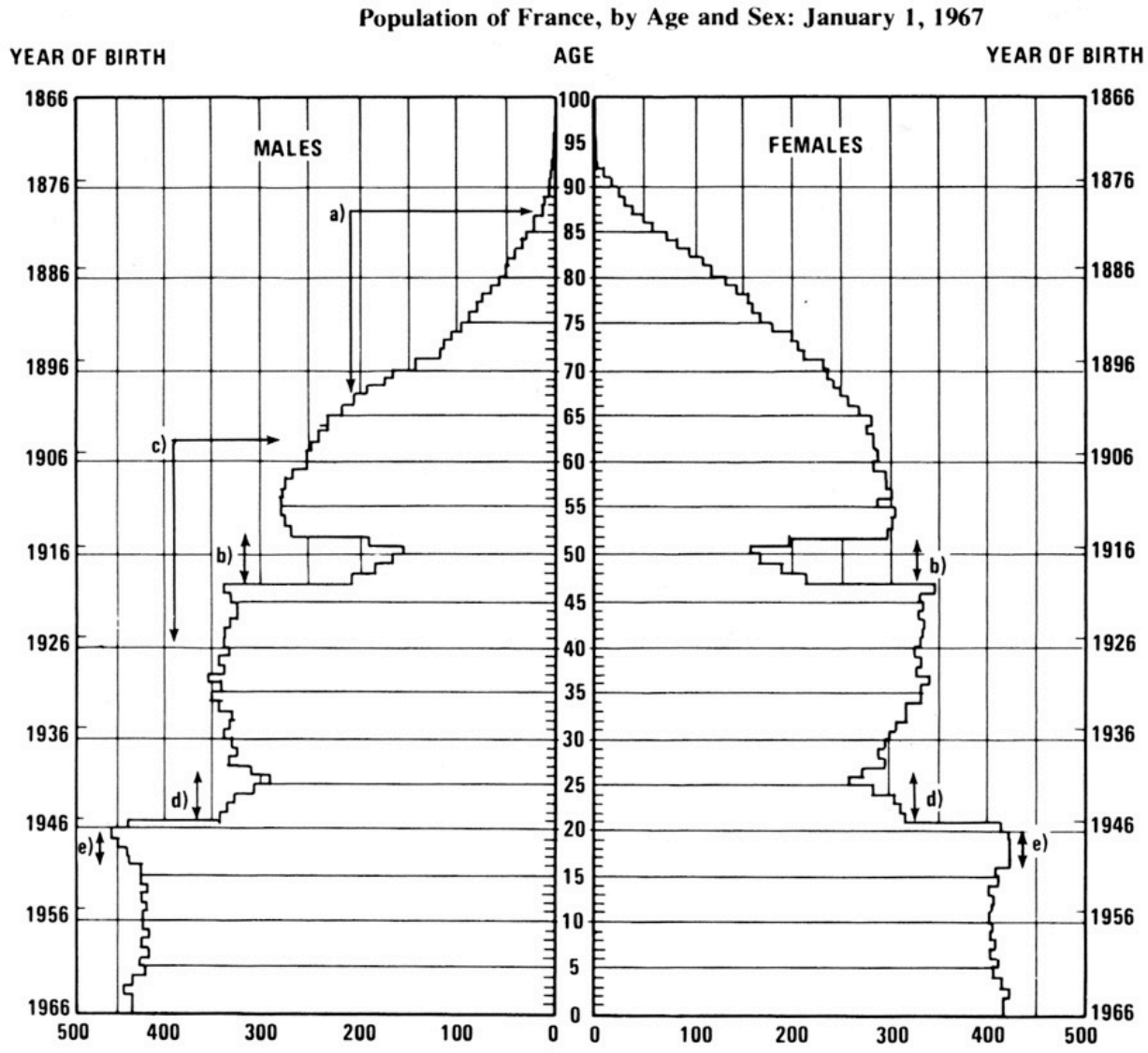
First axis (oft. horiz.): Nominal or Ordinal variable

Second axis: count of something (ratio)

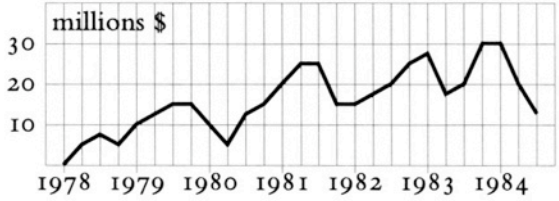
often convert Quantitative to Ordinal by binning (danger!)



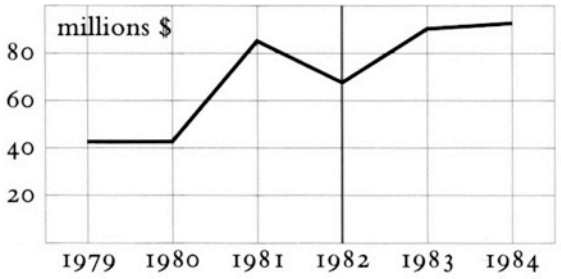
J. Hjort. Age composition of herring catches. 1914



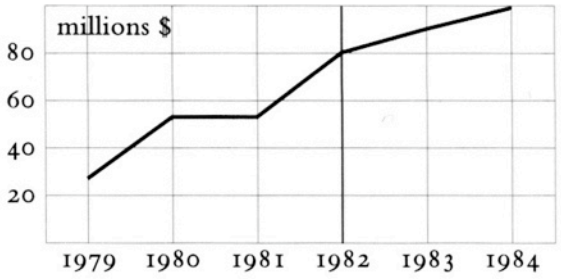
H.S. Shyrock & J.S. Siegel. Rendering of French government population data. 1973



Above, this chart shows *quarterly* revenue data in a financial graphic for a legal case. Several dips in revenue are visible.



Aggregating the quarterly data into years, this chart above shows revenue by *fiscal year* (beginning July 1, ending June 30). Note the dip in 1982, the basis of a claim for damages.



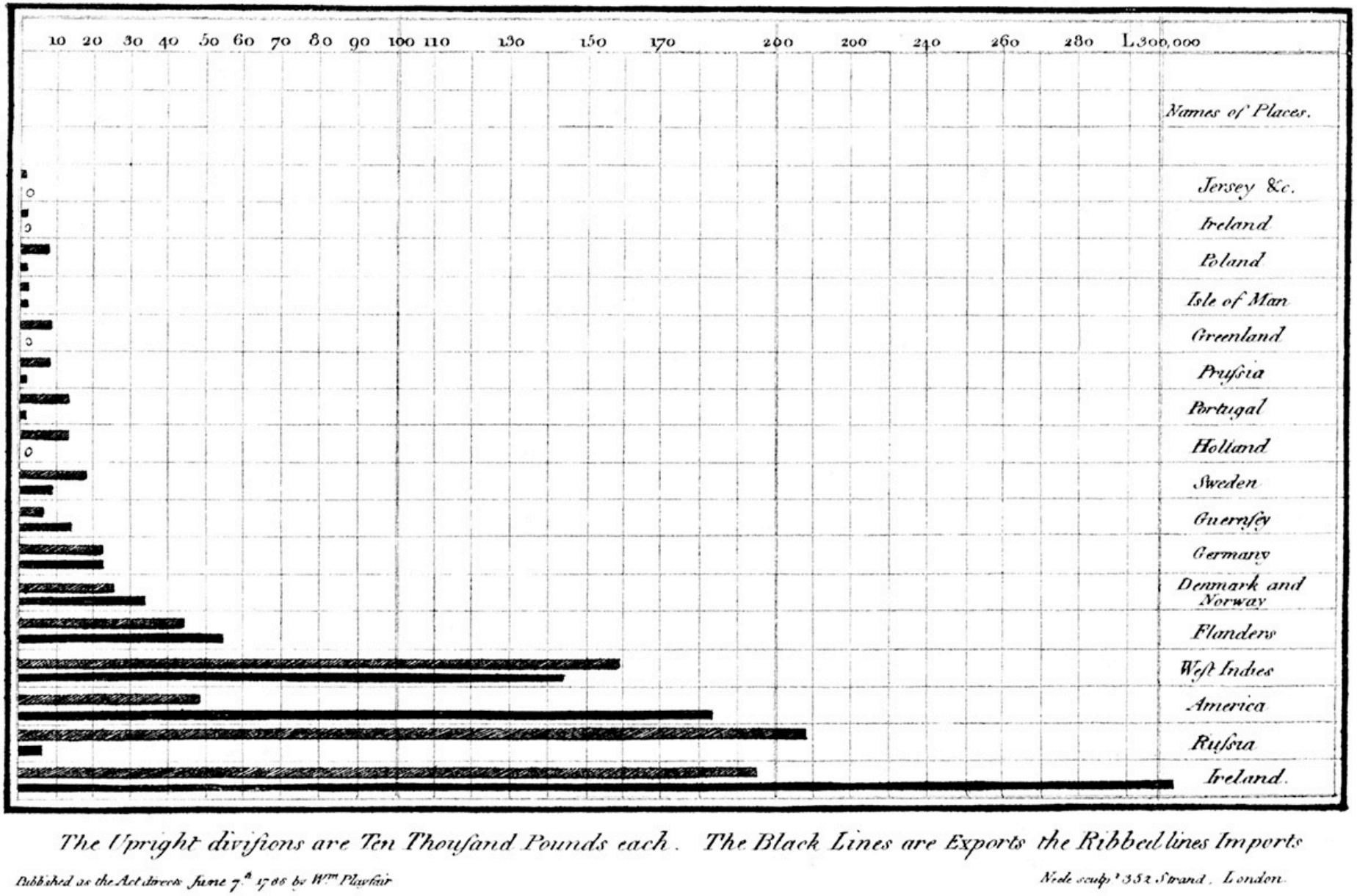
Shown above are the same quarterly revenue data added up into *calendar years*. The 1982 dip has vanished.

Bar charts

First axis (oft. horiz.): Nominal or Ordinal variable

Second axis: ratio quantity (ratio—length)

less appropriate for non-ratio quantities
(implied meaningful zero)


Exports and Imports of SCOTLAND to and from different parts for one Year from Christmas 1780 to Christmas 1781
10 20 30 40 50 60 70 80 90 100 110 130 150 170 200 200 240 260 280 L300,000
Names of Places.
Jersey &c.
Ireland
Poland
Isle of Man
Greenland
Prussia
Portugal
Holland
Sweden
Guernsey
Germany
Denmark and Norway
Flanders
West Indies
America
Russia
Ireland.
The Upright divisions are Ten Thousand Pounds each. The Black Lines are Exports the Ribbed lines Imports
Published as the Act directs June 7th 1786 by Wm Playfair
Neele sculp 352 Strand, London.

Polar plots

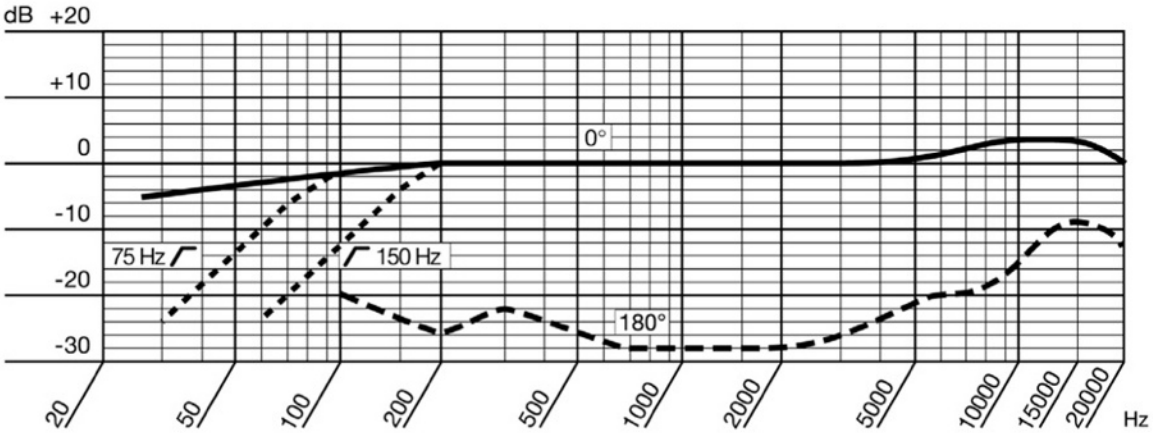
Angle: some relevant angle

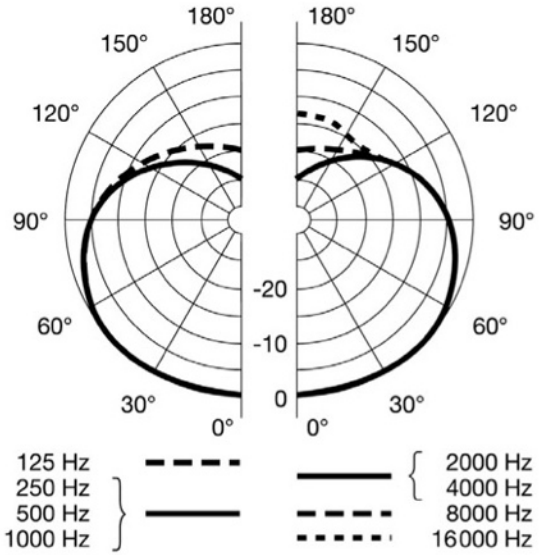
Radius: ratio quantity (ratio—length)

not appropriate for non-angular quantities

less appropriate for non-ratio quantities

beware of area exaggeration





AKG Acoustics. Performance data for C451B microphone. 1973

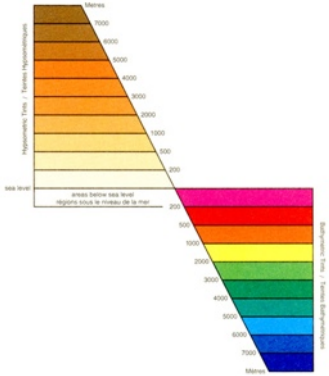
Color maps

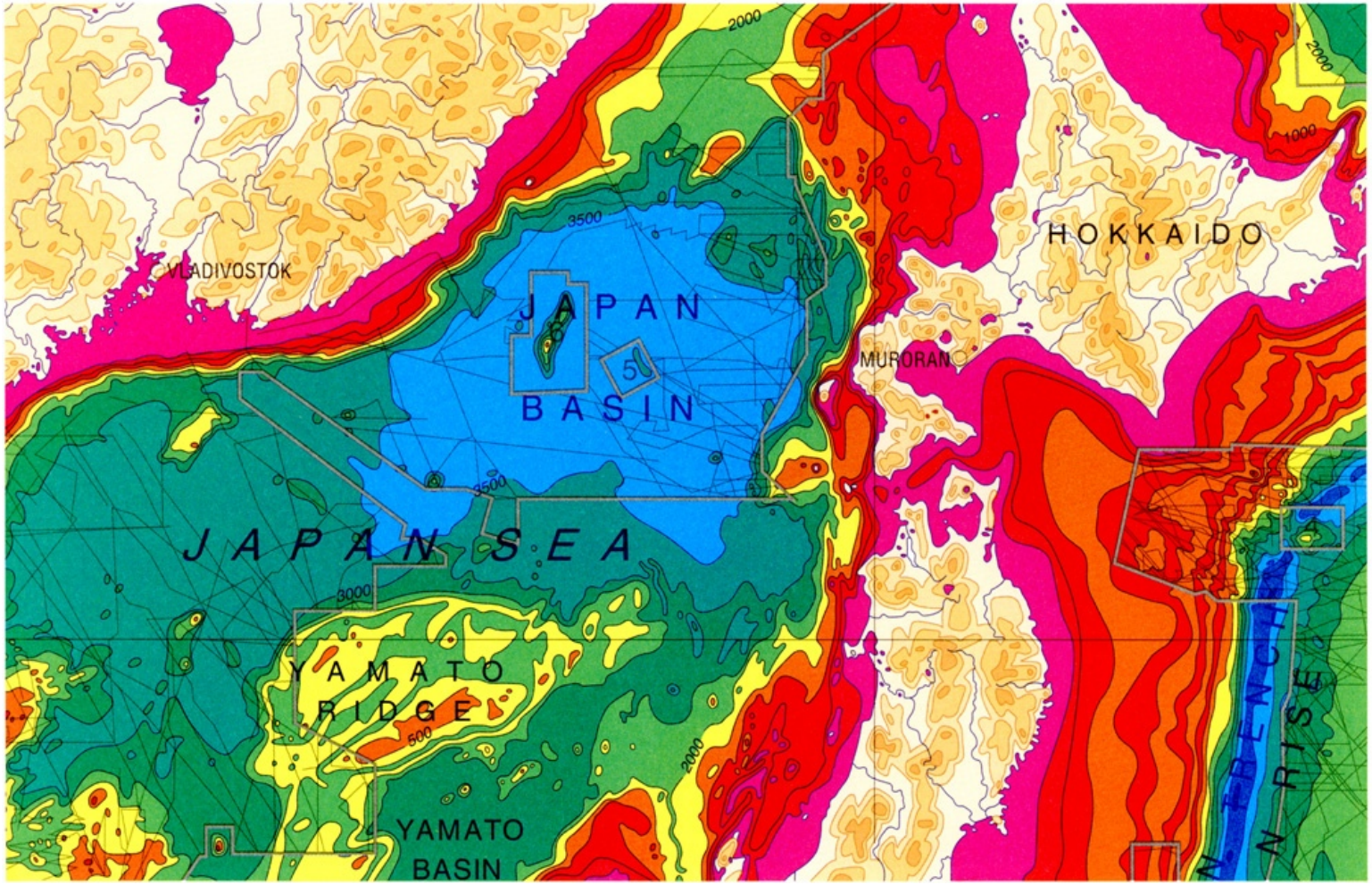
Position: position, direction, or more abstract mapping

Color: interval or ratio quantity

be careful to map color attributes appropriately!

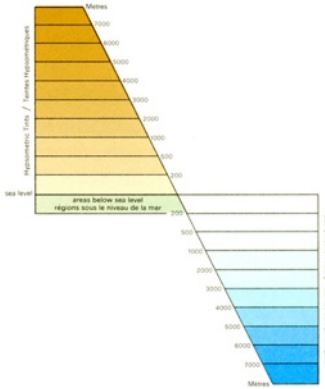
[from Tufte, *Visual Explanations*]

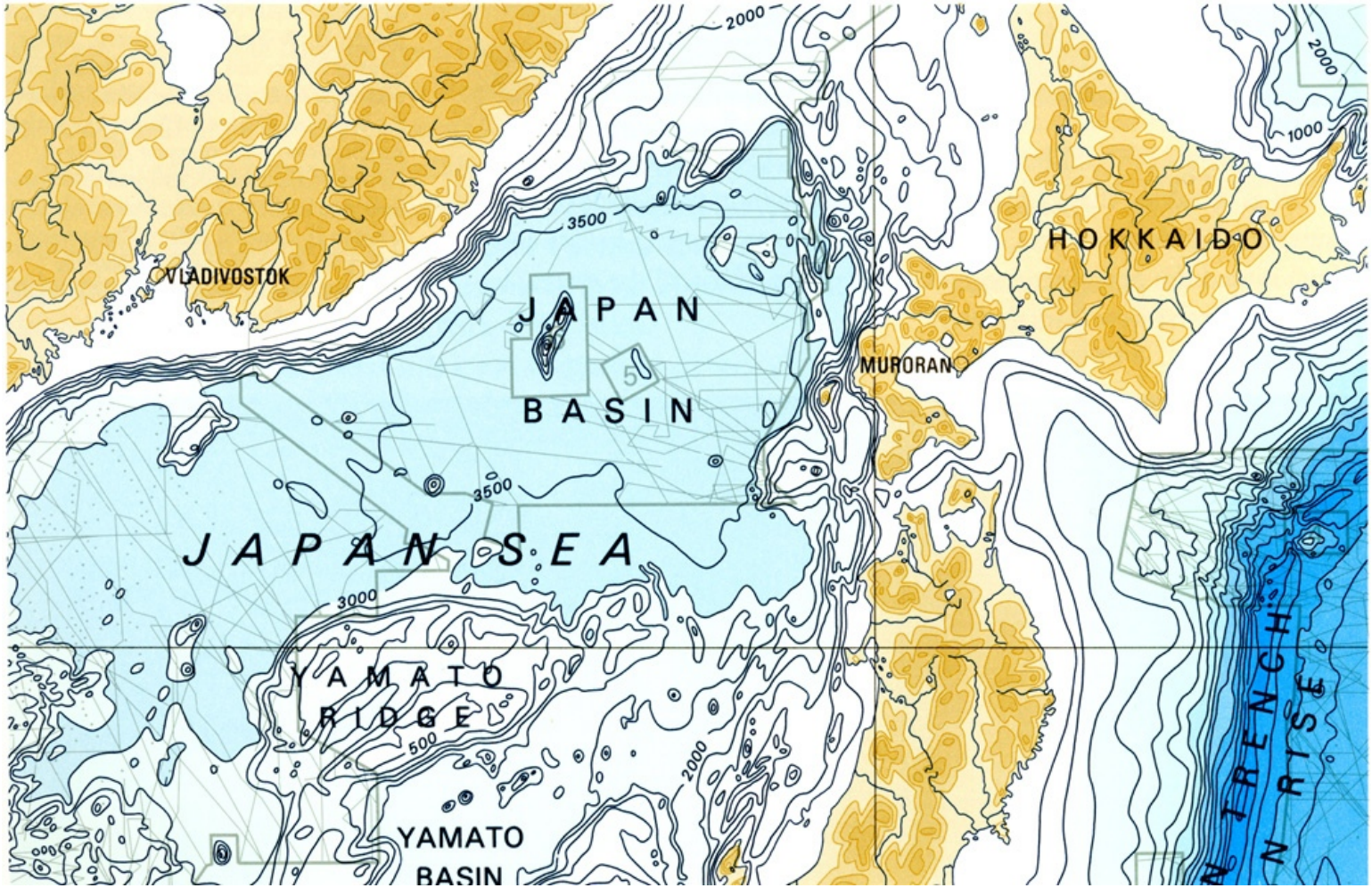




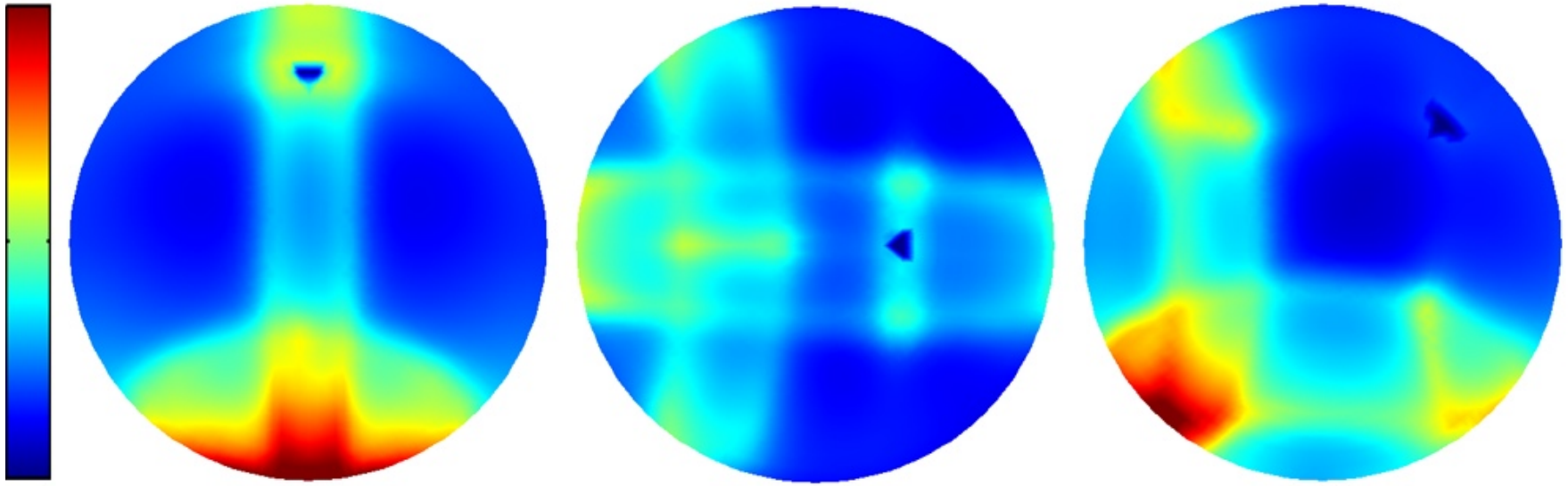
International Hydrographic Organization, 1984
(as deliberately corrupted by Tufte)

[from Tufte, *Visual Explanations*]

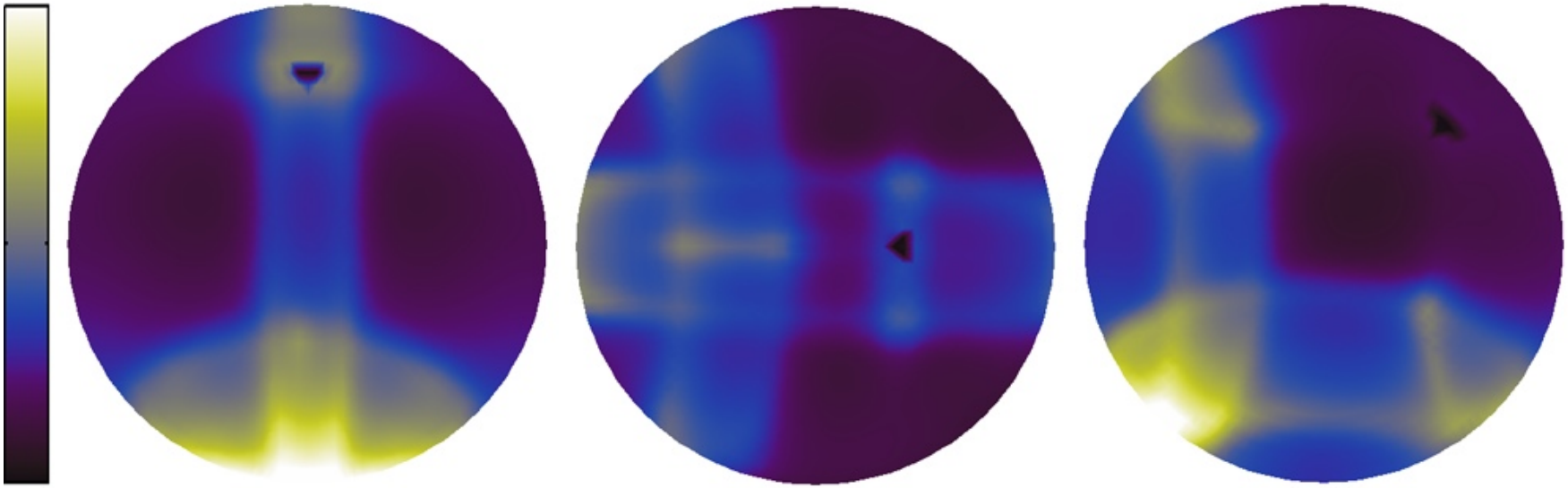




International Hydrographic Organization, 1984



P. Irawan & S. Marschner. Scattering data for polyester cloth. 2007
(Matlab default colormap)



P. Irawan & S. Marschner. Scattering data for polyester cloth. 2007
(increasing value colormap)

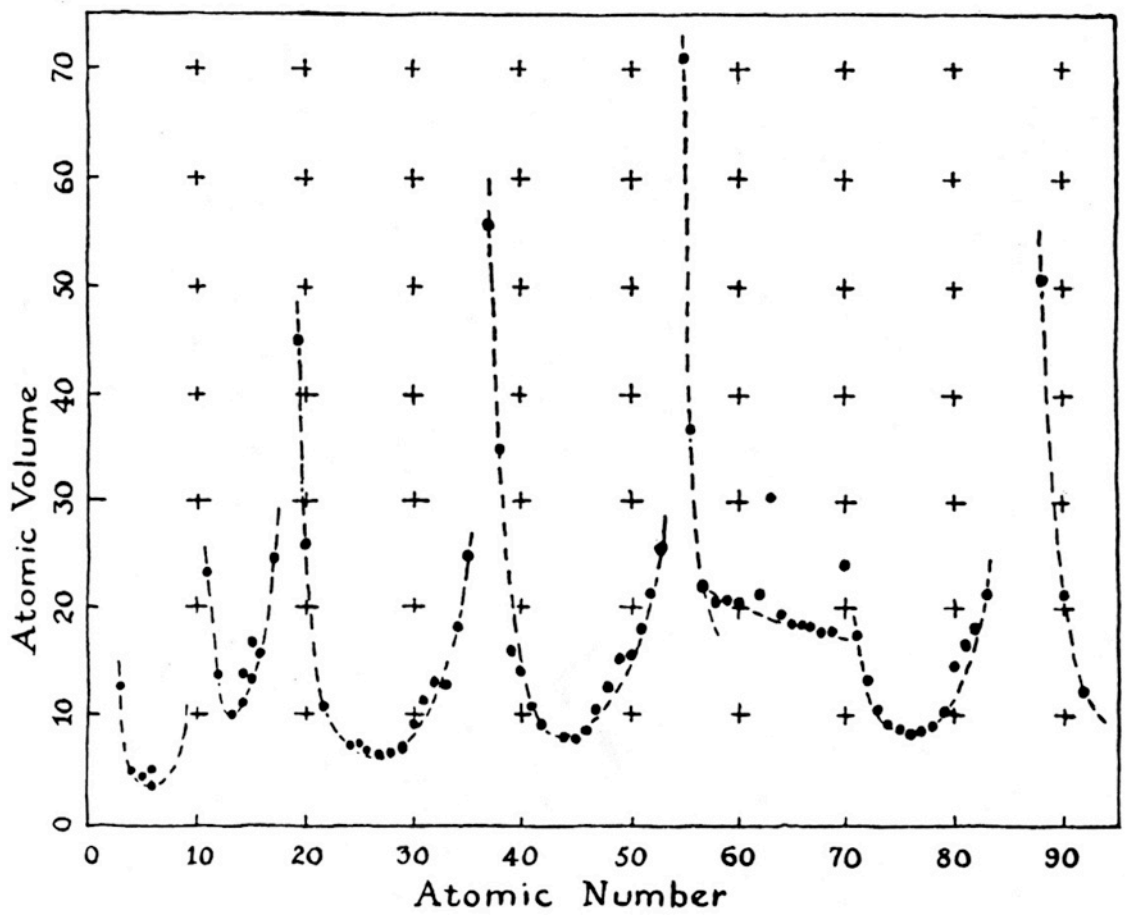
“Graphical excellence”

Maximizing data:ink ratio

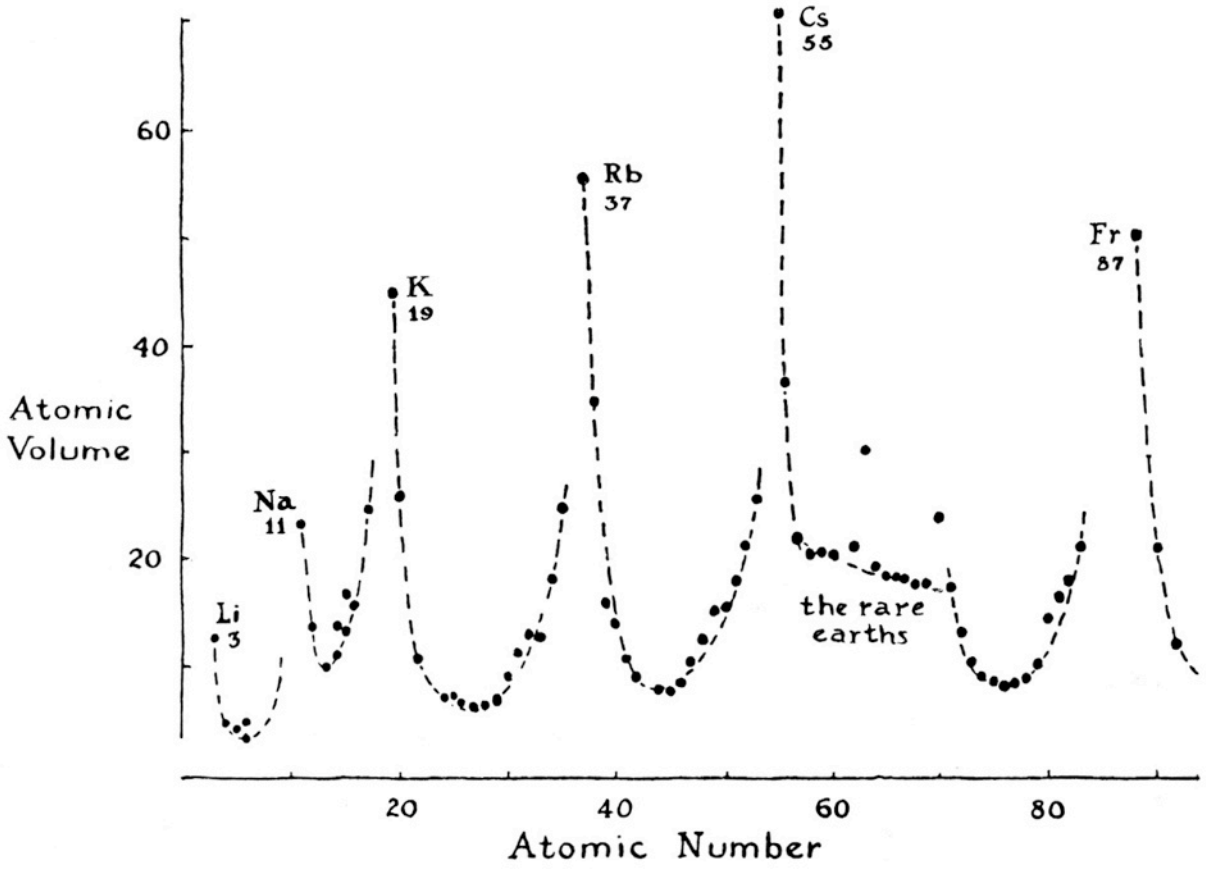
"A sentence should contain no unnecessary words, a paragraph no unnecessary sentences, for the same reason that a drawing should have no unnecessary lines and a machine no unnecessary parts."

—William Strunk, Jr.

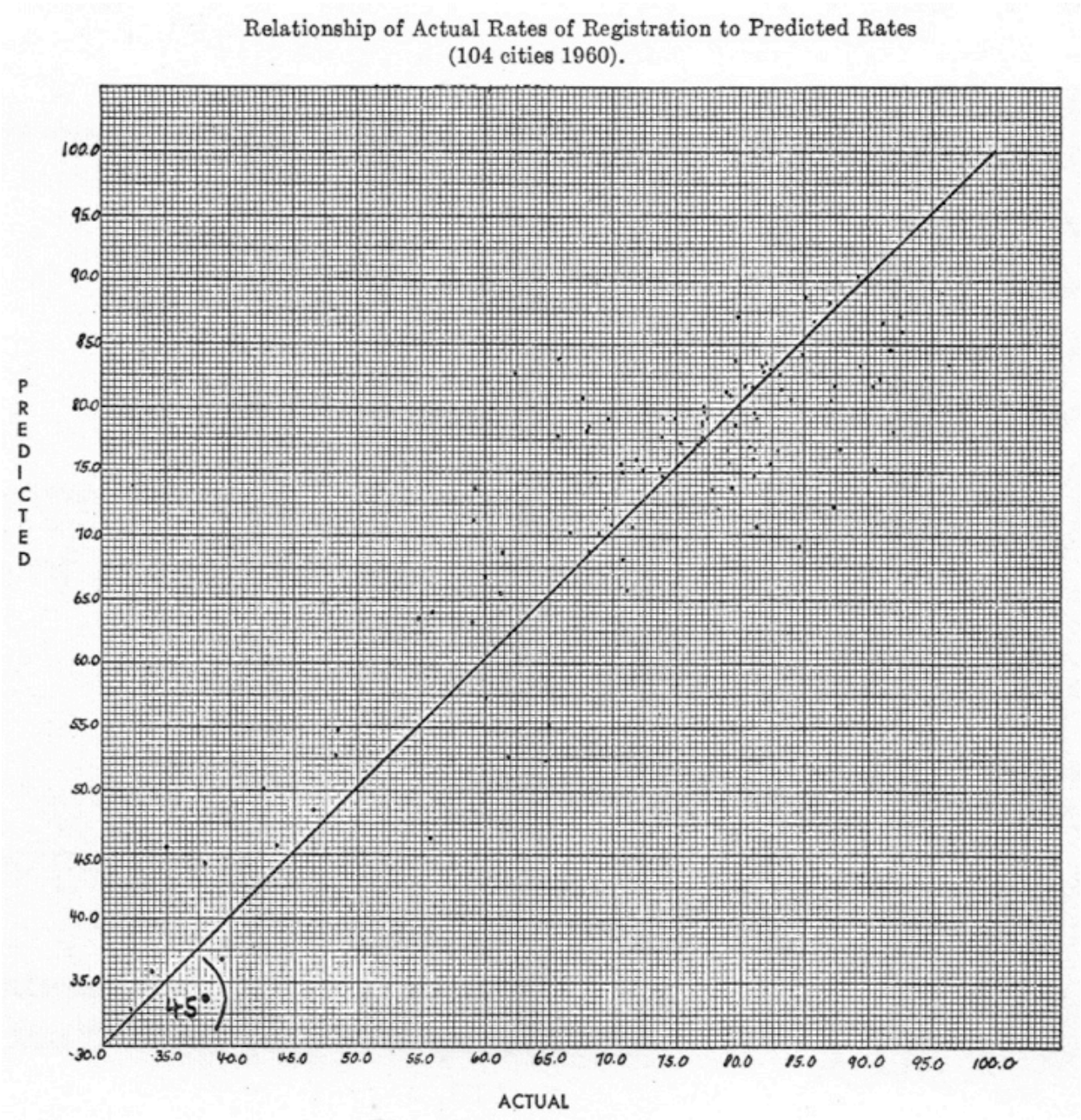
“Chart-junk”

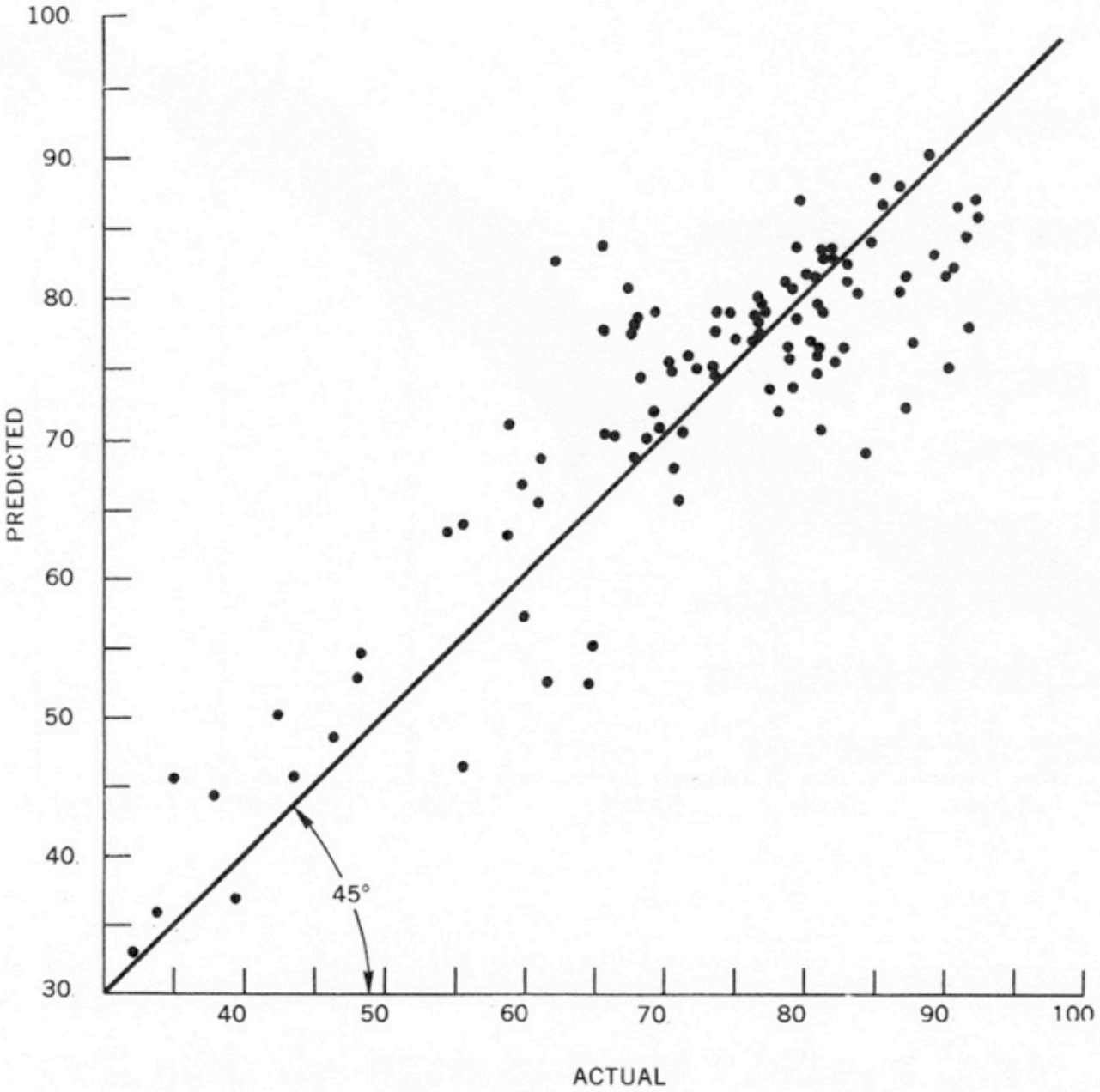


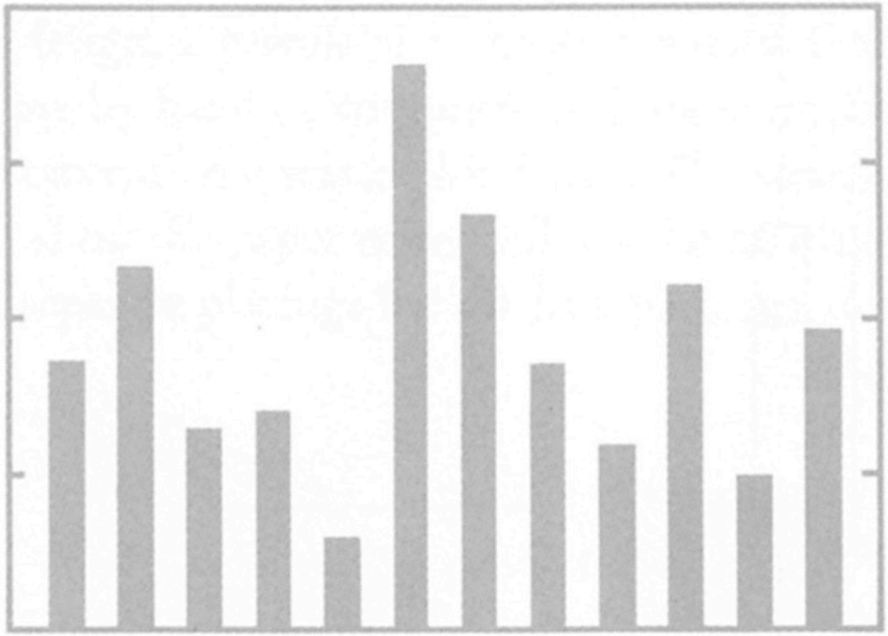
R. Hayward. From L. Pauling, *General Chemistry*. 1947

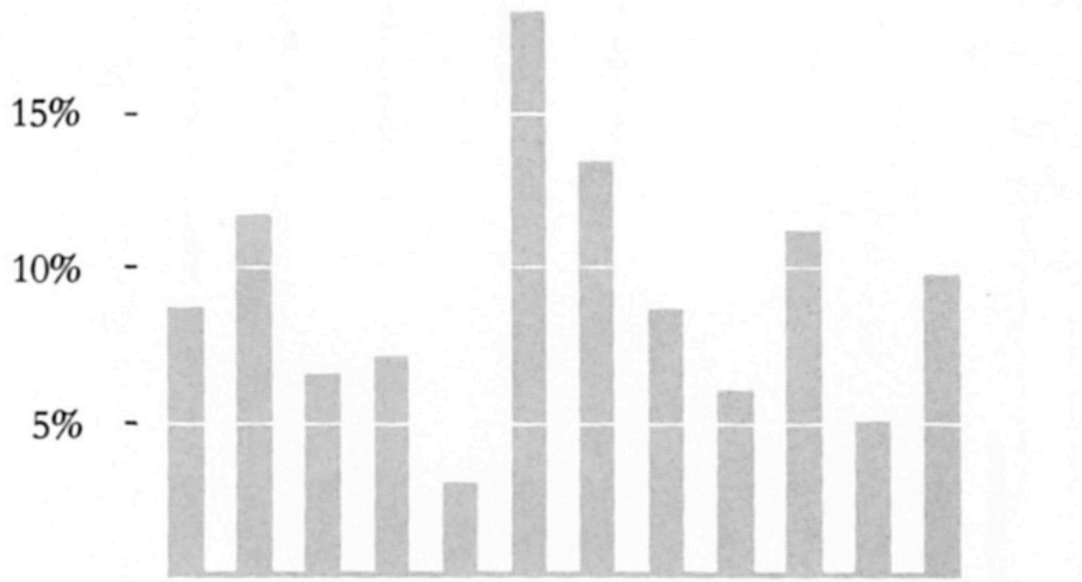


as modified by Tufte


Relationship of Actual Rates of Registration to Predicted Rates
(104 cities 1960).
PREDICTED
ACTUAL
100.0
95.0
90.0
85.0
80.0
75.0
70.0
65.0
60.0
55.0
50.0
45.0
40.0
35.0
30.0
35.0
40.0
45.0
50.0
55.0
60.0
65.0
70.0
75.0
80.0
85.0
90.0
95.0
100.0
45°

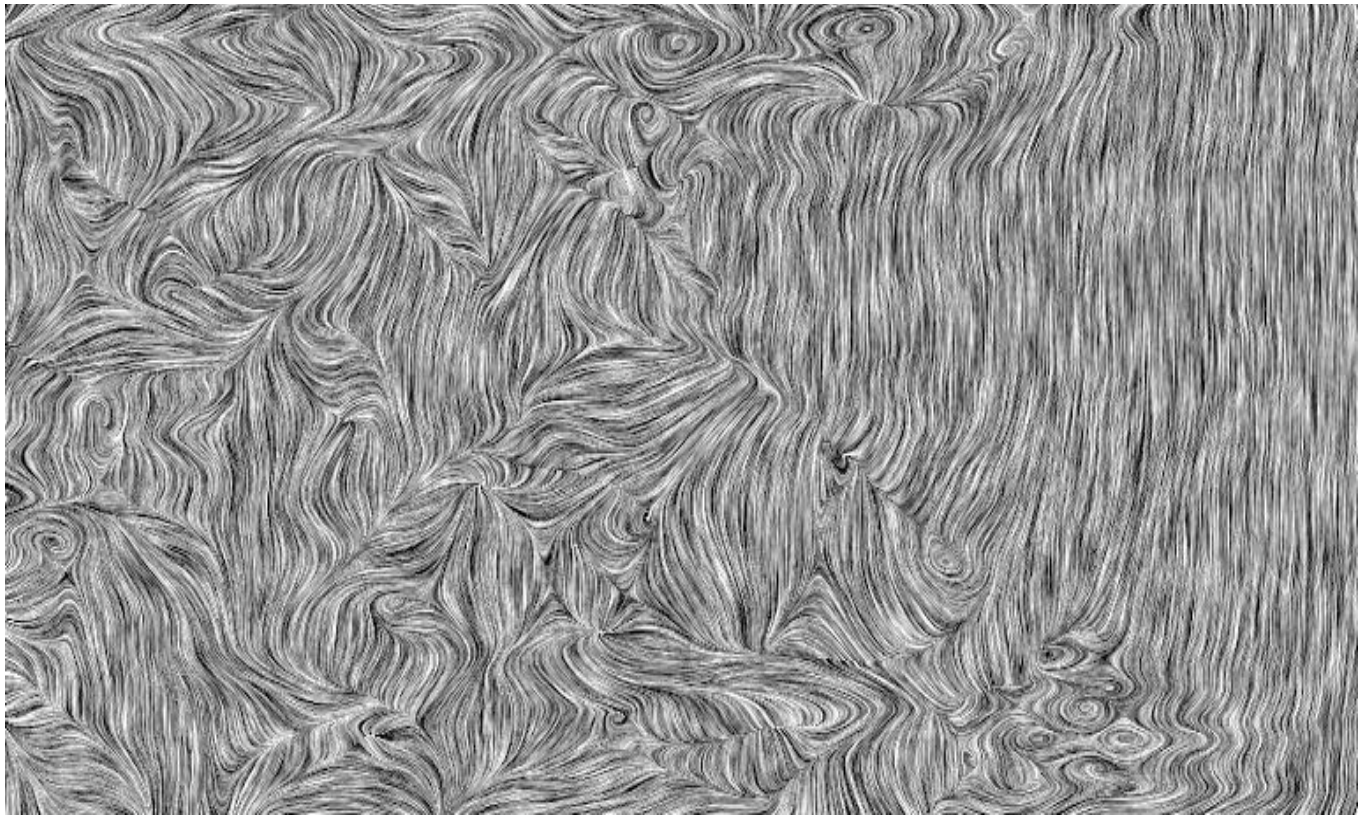

100
90
80
70
60
50
40
30
PREDICTED
45°
40
50
60
70
80
90
100
ACTUAL



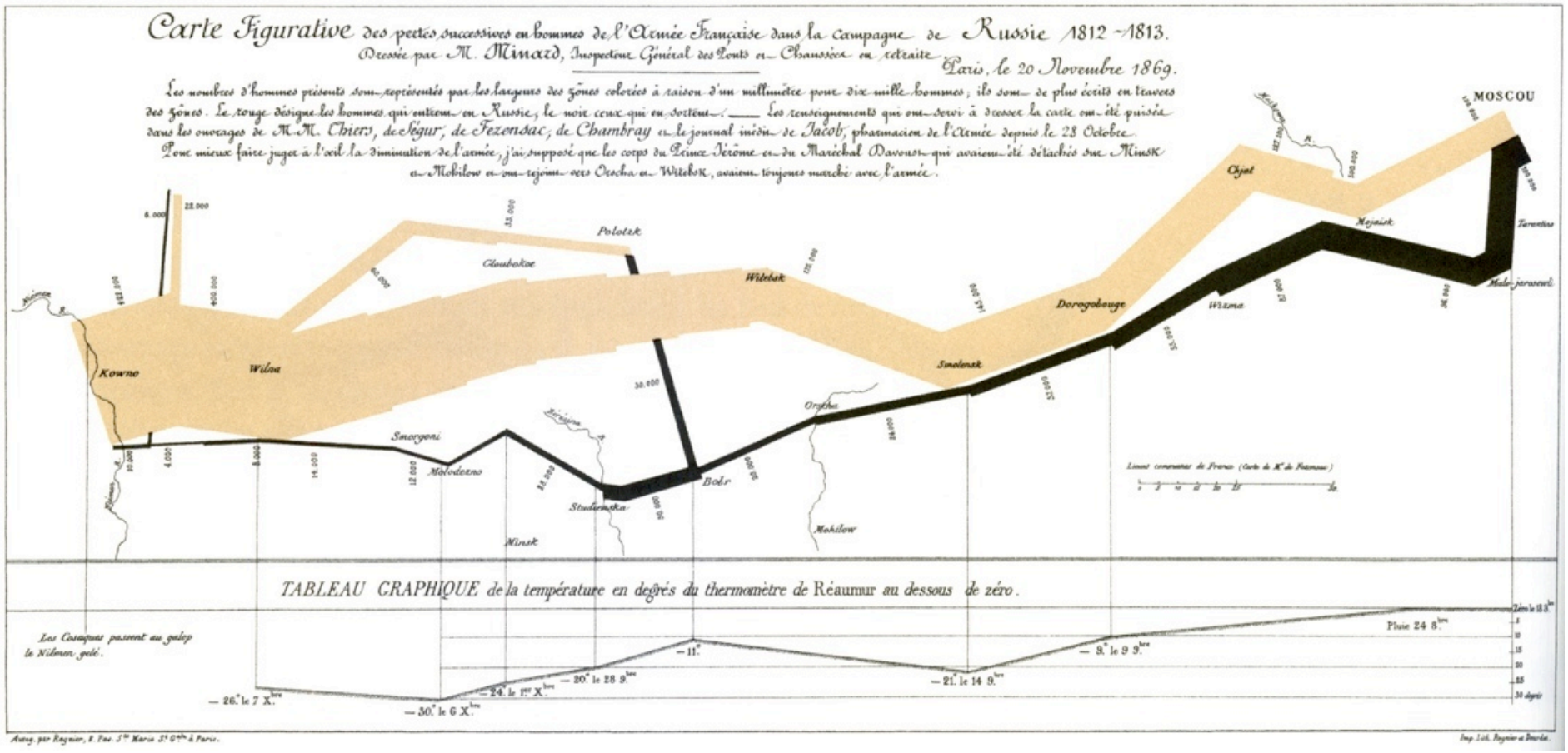

15%
10%
5%

Tufte's proposal for *range frames*

Line Integral Convolution for vector fields



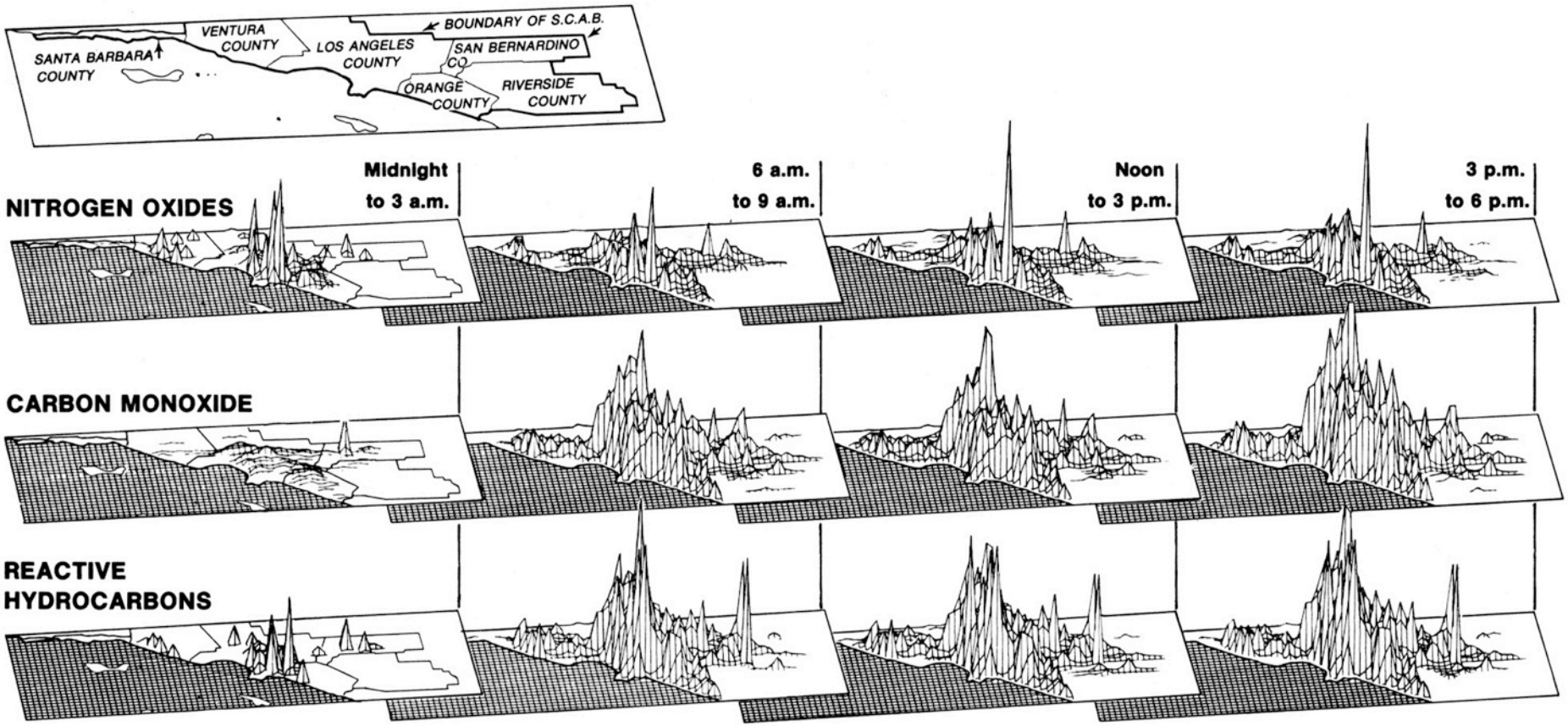
Cabral and Leedom, SIGGRAPH 1993



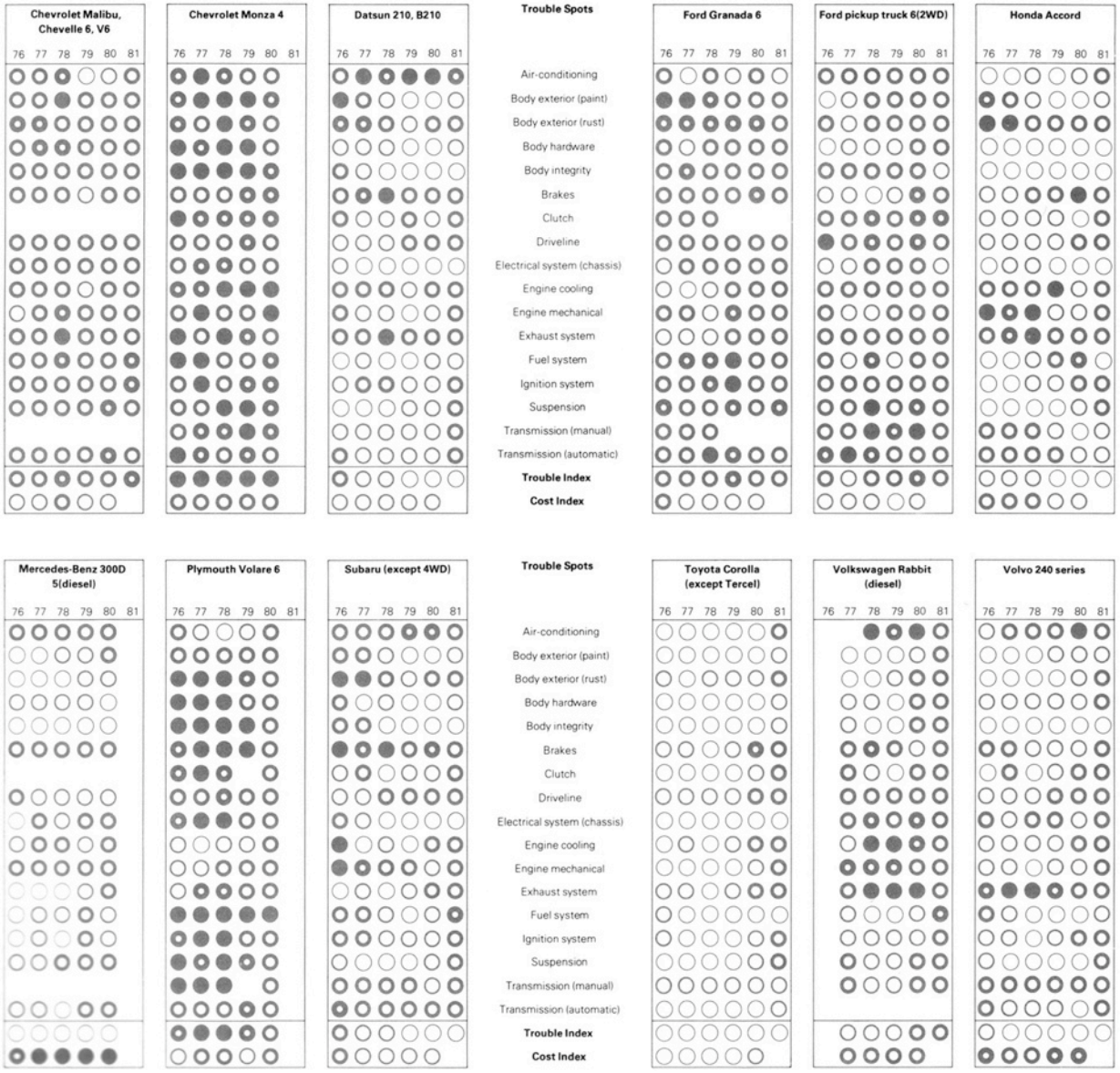
J.C. Minard. Depiction of losses during French Army march to (and retreat from) Moscow, 1812–1813.

Small Multiples

A set of small figures following a common design that can be readily compared



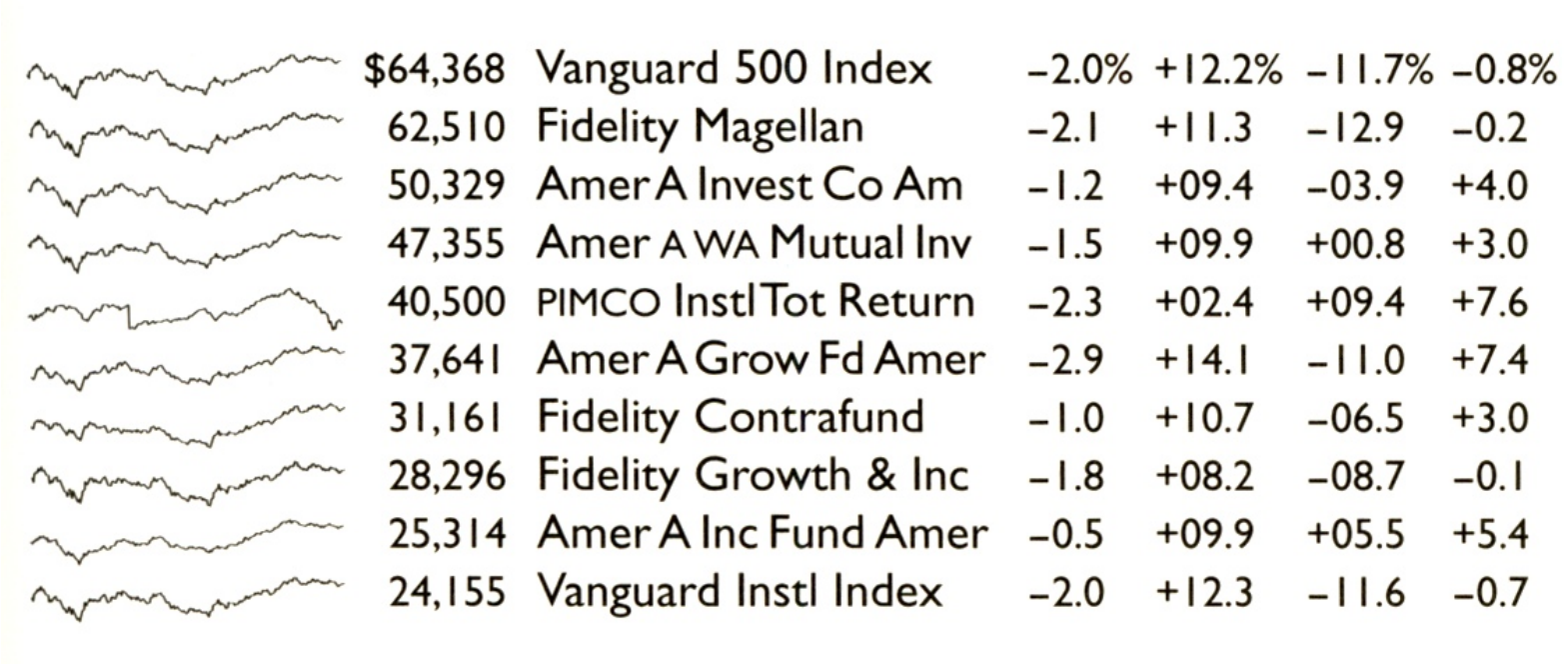
Los Angeles Times / G.J. McRae. 1979



Consumer Reports. Display of historical automobile reliability data. 1982

Popular mutual funds, based on assets under management.

ASSETS (MIL.)	FUND	RETURN 4 WKS.	2003	3-YR.	5-YR.
$64,368	Vanguard Index 500 Index	– 2.0%	+12.2%	– 11.7%	– 0.8%
62,510	Fidelity Magellan	– 2.1	+11.3	– 12.9	– 0.2
50,329	Amer A Invest Co of Am	– 1.2	+09.4	– 3.9	+ 4.0
47,355	Amer A WA Mutual Inv	– 1.5	+09.9	+ 00.8	+ 3.0
40,500	PIMCO Instl Tot Return	– 2.3	+02.4	+ 09.4	+ 7.6
37,641	Amer A Grow Fd of Amer	– 2.9	+14.1	– 11.0	+ 7.4
31,161	Fidelity Contrafund	– 1.0	+10.7	– 6.5	+ 3.0
28,296	Fidelity Growth & Inc	– 1.8	+ 8.2	– 8.7	– 0.1
25,314	Amer A Inc Fund of Amer	– 0.5	+ 9.9	+ 05.5	+ 5.4
24,155	Vanguard Instl Index	– 2.0	+12.3	– 11.6	– 0.7



$64,368	Vanguard 500 Index	−2.0%	+12.2%	−11.7%	−0.8%
62,510	Fidelity Magellan	−2.1	+11.3	−12.9	−0.2
50,329	Amer A Invest Co Am	−1.2	+09.4	−03.9	+4.0
47,355	Amer A WA Mutual Inv	−1.5	+09.9	+00.8	+3.0
40,500	PIMCO Instl Tot Return	−2.3	+02.4	+09.4	+7.6
37,641	Amer A Grow Fd Amer	−2.9	+14.1	−11.0	+7.4
31,161	Fidelity Contrafund	−1.0	+10.7	−06.5	+3.0
28,296	Fidelity Growth & Inc	−1.8	+08.2	−08.7	−0.1
25,314	Amer A Inc Fund Amer	−0.5	+09.9	+05.5	+5.4
24,155	Vanguard Instl Index	−2.0	+12.3	−11.6	−0.7

E. Tufte "sparklines"

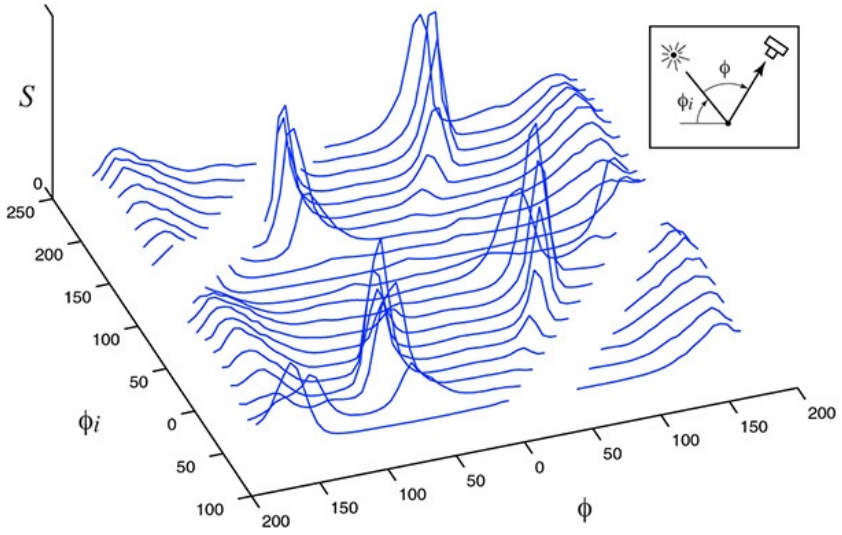


Figure 6: A measurement of scattering in the normal plane from a hair with substantial eccentricity. Bright glints appear whose location and strength depend on the orientation of the hair [subject HM].

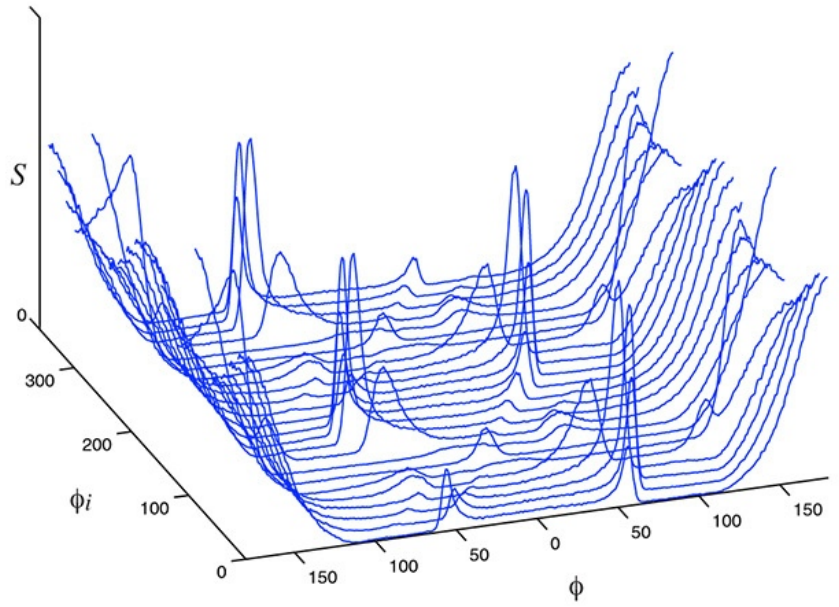
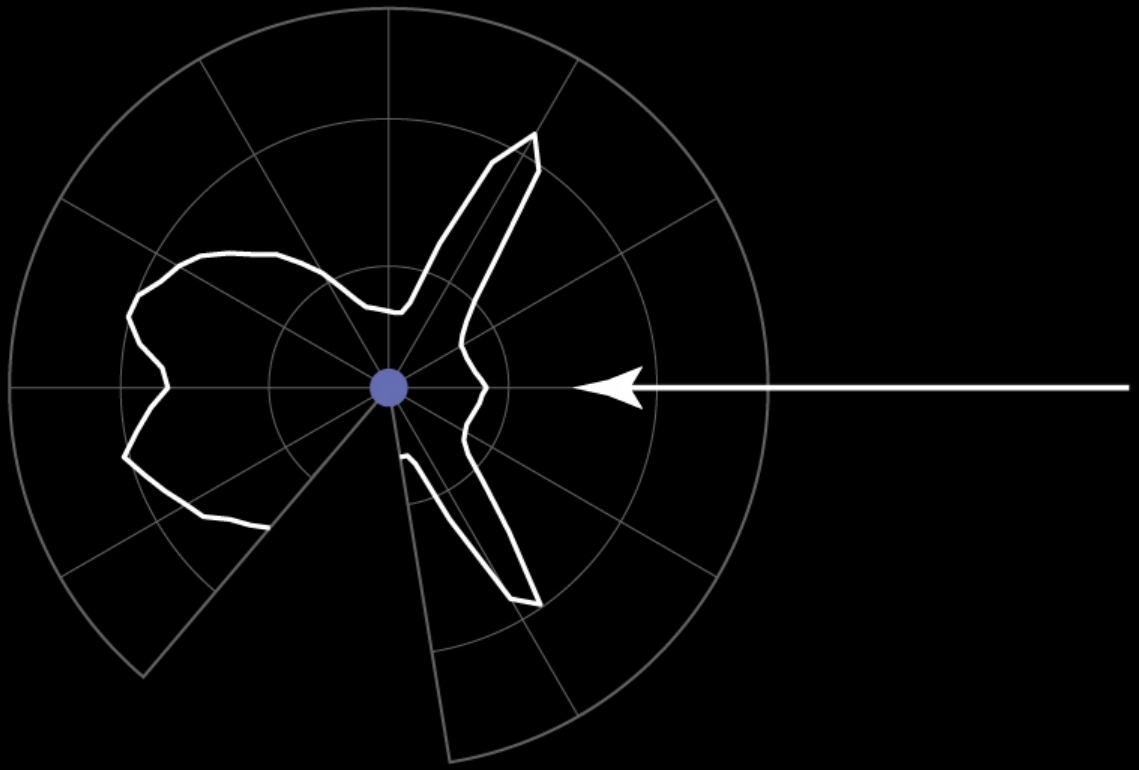


Figure 7: A photon-tracing simulation of scattering from a rough elliptical fiber. The axes are the same as in Figure 6.

S.R. Marschner. Presentation of fiber scattering data using default MATLAB plots. 2002



S.R. Marschner. Re-presentation using polar coordinates and small multiples. 2003
(thanks to François Guimbretière)

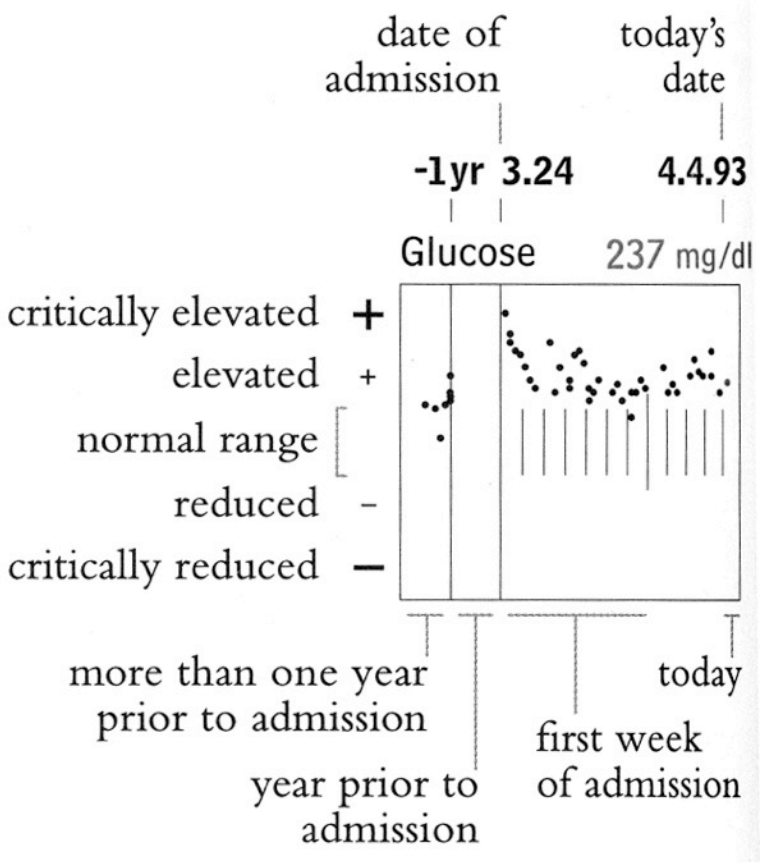
Marschner, Jensen, Cammarano, Worley, and Hanrahan. "Light Scattering from Human Hair Fibers," *SIGGRAPH 2003*.

hair
rotation
illumination

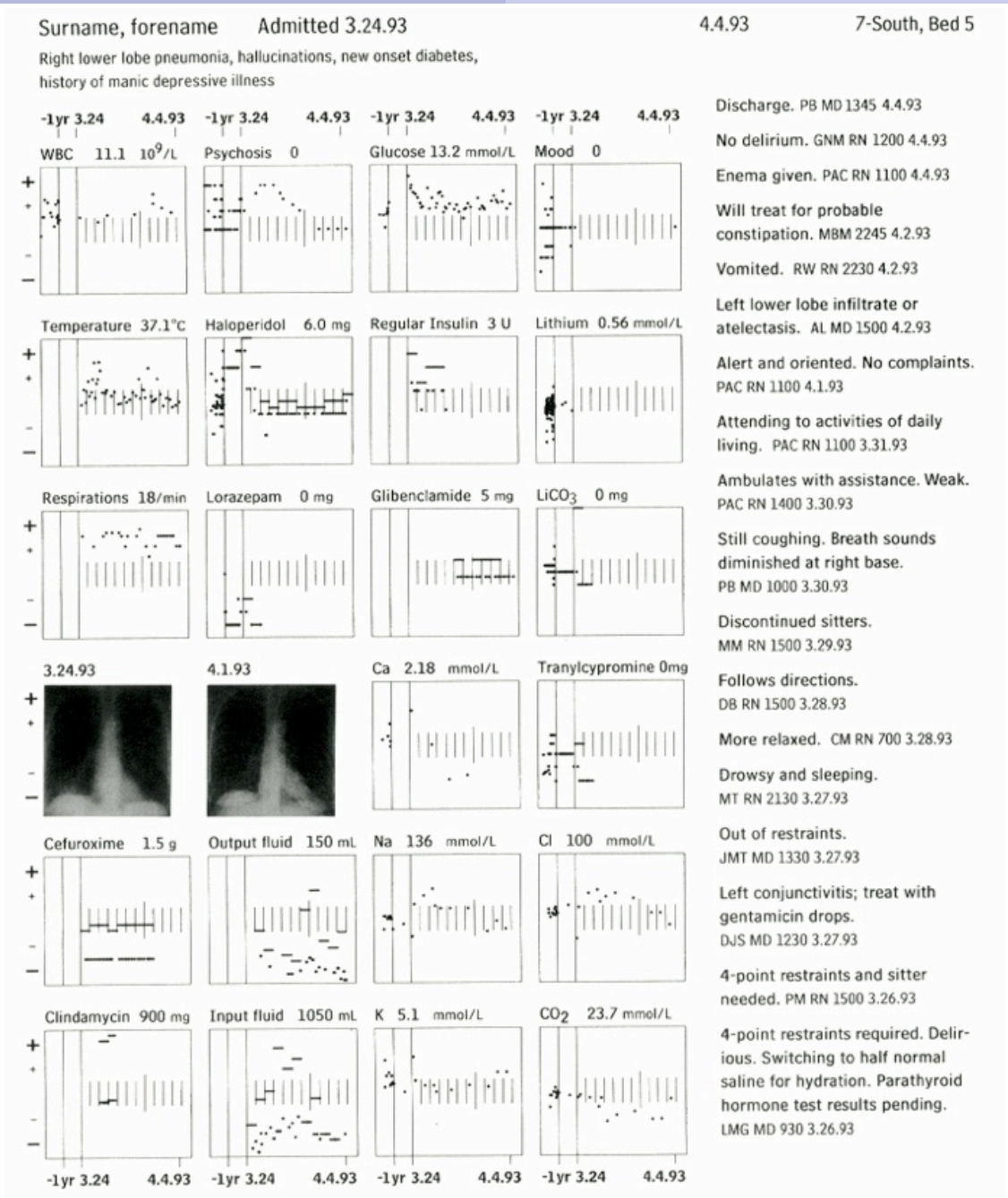
hair
rotation
illumination

hair
rotation
illumination

Visualization for medical records



S.M. Powsner & E.R. Tufte, *The Lancet* **344**:6 1994



S.M. Powsner & E.R. Tufte, *The Lancet* **344**:6 1994