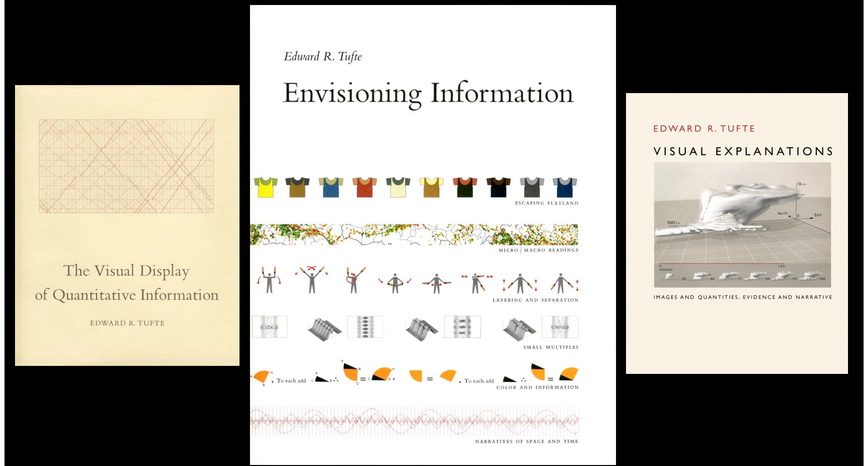
Tufte's Design Principles

James Eagan

Adapted from slides
by John Stasko

Envisioning Information



Graphical excellence is the well-designed presentation of interesting data—a matter of substance, of statistics, and of design.

Graphical excellence consists of complex ideas communicated with clarity, precision and efficiency.

Graphical excellence is that which gives to the viewer the greatest number of ideas in the shortest time with the least ink in the smallest space.

Graphical excellence is nearly always multivariate.

Graphical excellence requires telling the truth about the data.

Data graphics should complement what humans do well.

“We thrive in information-thick worlds because of our marvelous and everyday capacities to select, edit, single out, structure, highlight, group, pair, merge, harmonize, synthesize, focus, organize, condense, reduce, boil down, choose, …

[Vol. 2, p. 50]

categorize, catalog, classify, list, abstract, scan, look into, idealize, isolate, discriminate, distinguish, screen, pigeonhole, pick over, sort, integrate, blend, inspect, filter, lump, skip, smooth, chunk, average, approximate, cluster, …

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aggregate, outline, summarize, itemize, review, dip into, flip through, browse, glance into, leaf through, skim, refine, enumerate, glean, synopsize, winnow the wheat from the chaff, and separate the sheep from the goats.”

[Vol. 2, p. 50]

Graphical integrity.

Design aesthetics.

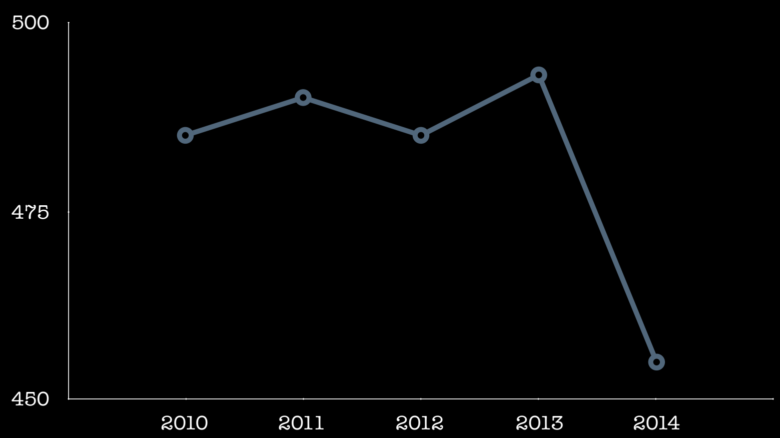
Graphical integrity.

(Tell the truth.)

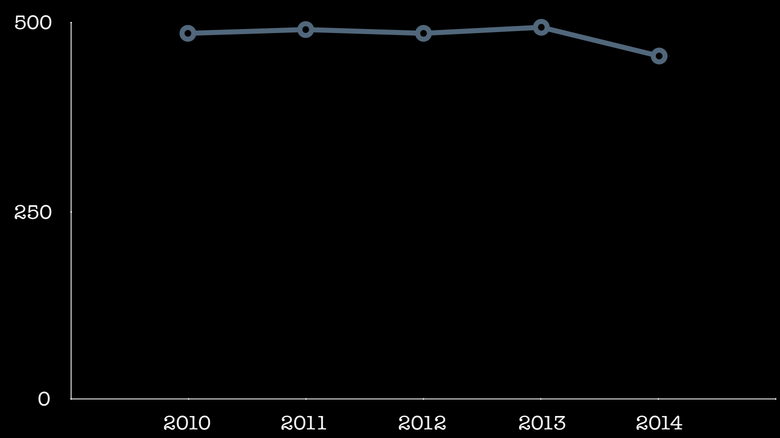
Design aesthetics.

(Do it effectively with clarity & precision.)

Stock market crash?



Show entire scale



Show in context

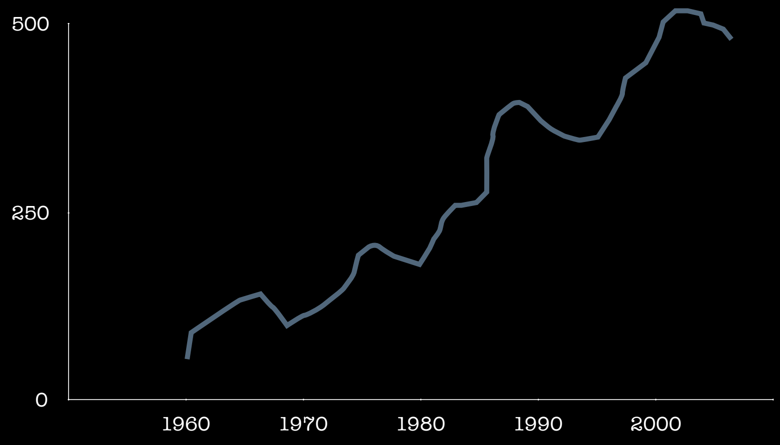
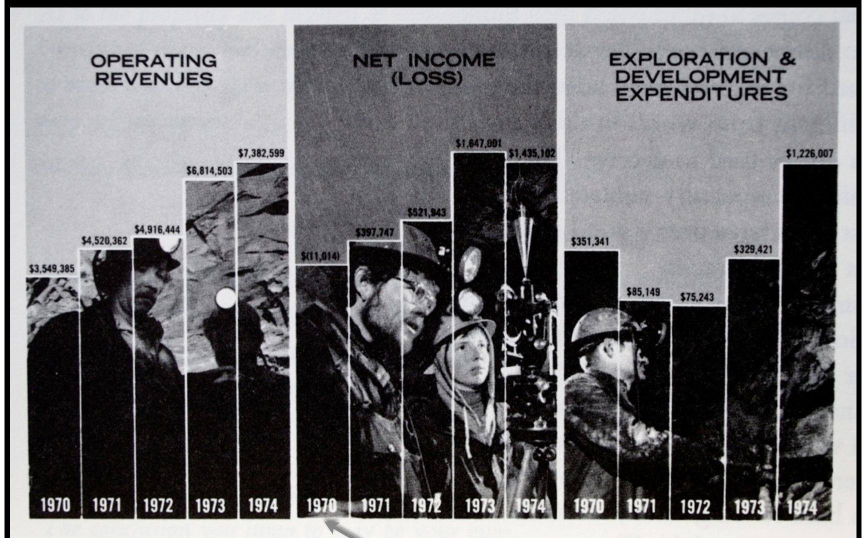


Chart integrity.

Where's the baseline?

What's the scale?

What's the context?



$(4,200,000)

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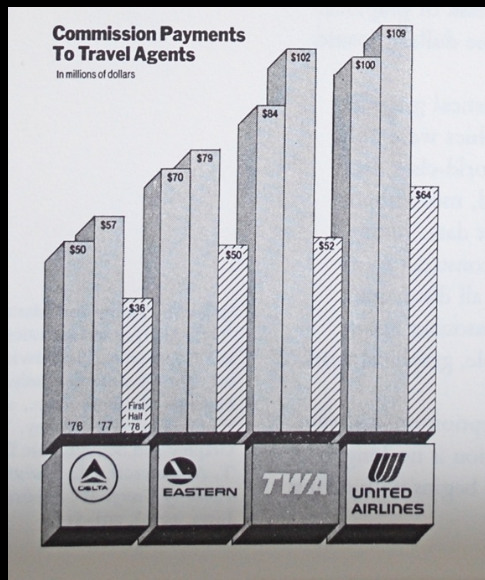
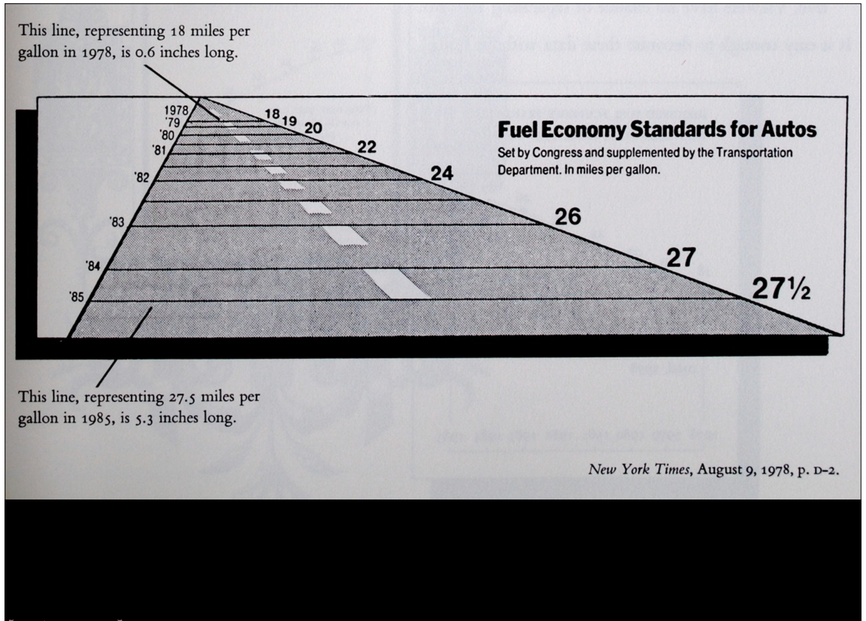
What's the component?



[Vol. 1, p. 54]



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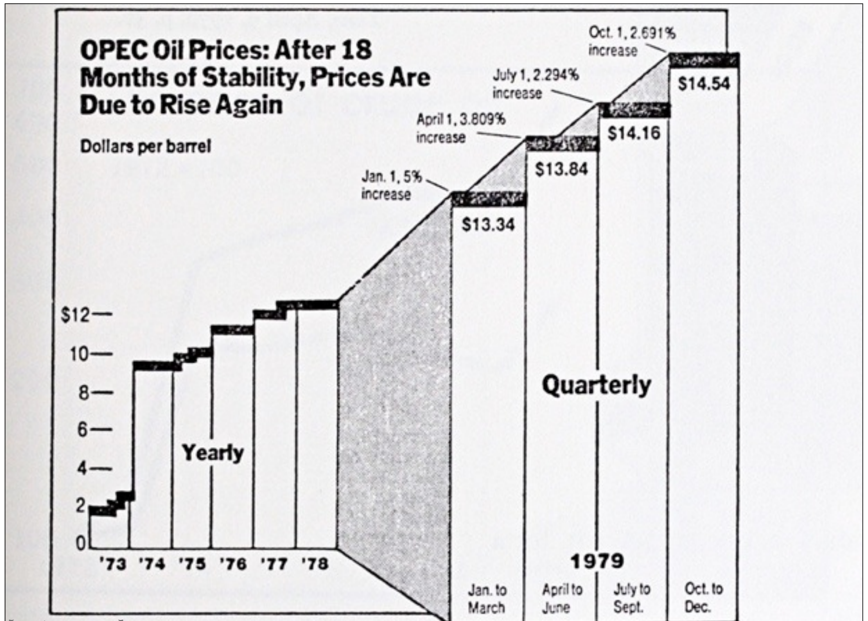

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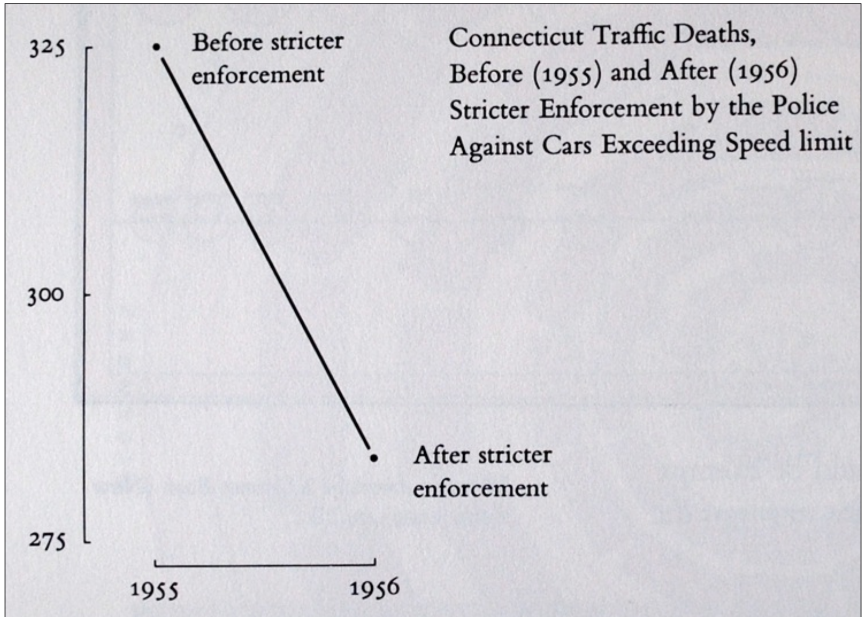

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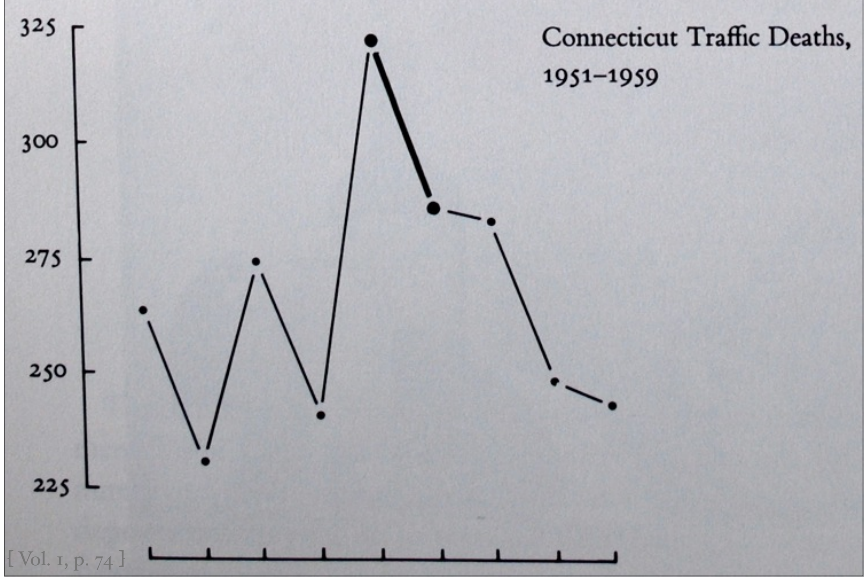
A few more data points add immensely to the account:



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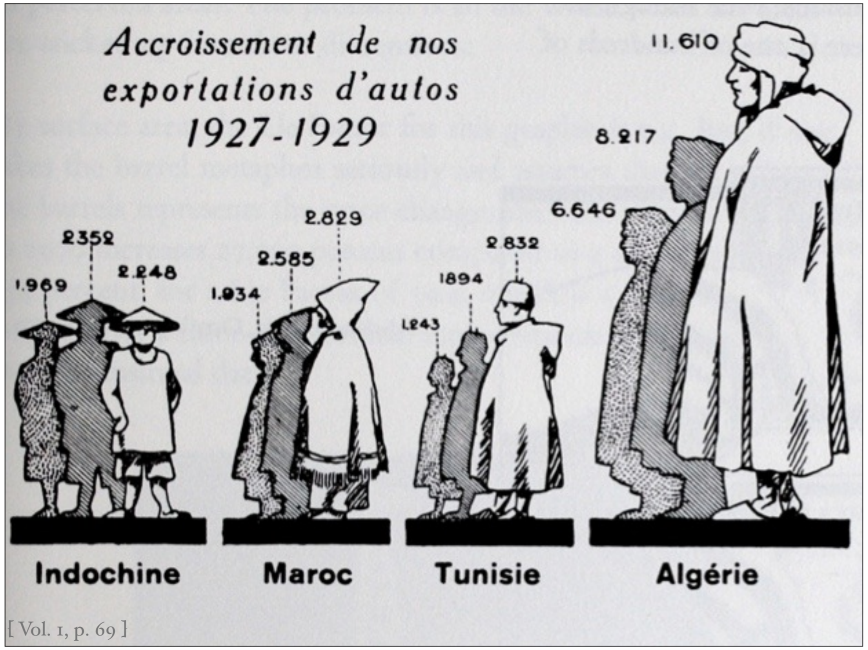
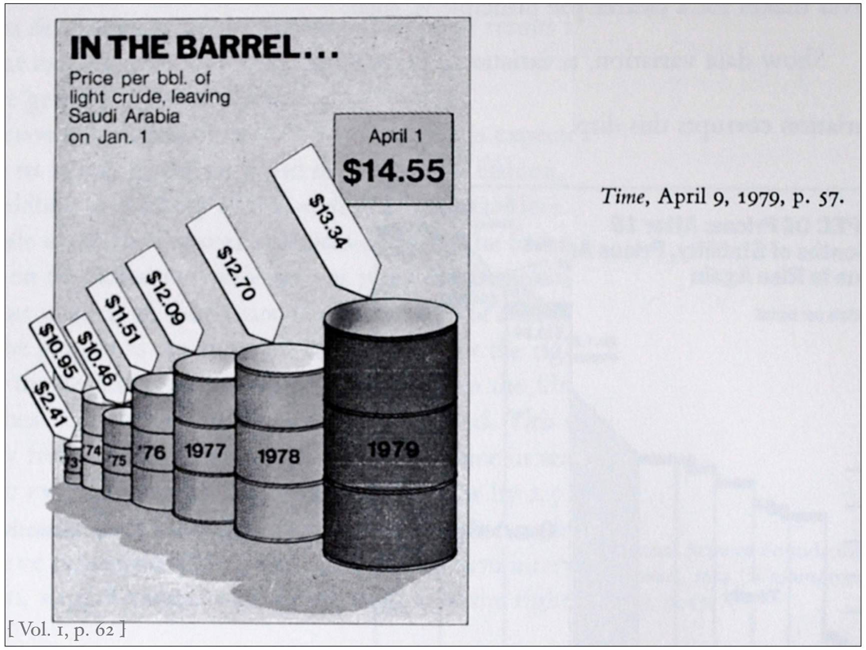
Watch size coding.

(height/width)
(area/volume)



[Vol. 1, p. 69]



[Vol. 1, p. 62]

Measuring Misrepresentation

- Visual attribute value should be directly proportional to data attribute value

$$\text{Lie factor} = \frac{\text{size of effect shown in graphic}}{\text{size of effect shown in data}}$$

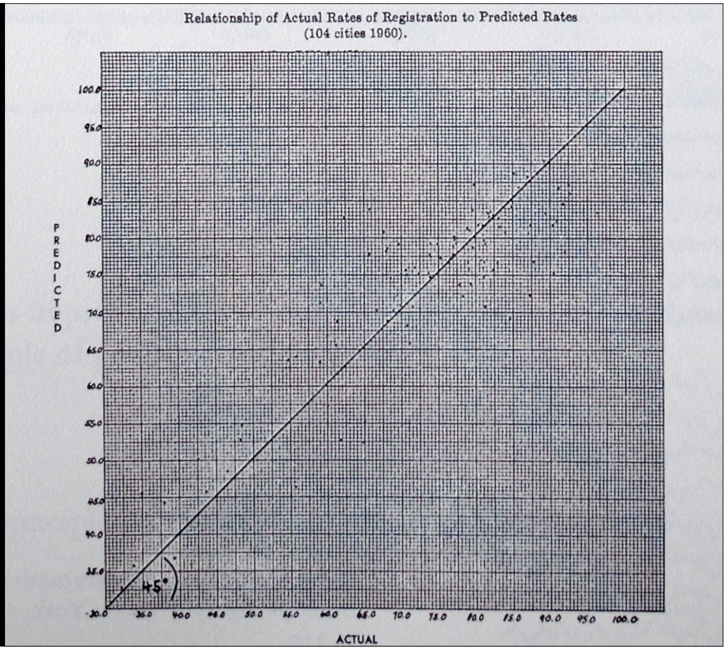
$$9.4 = \frac{4280}{454}$$

Design aesthetics

Set of principles to help guide designers.

Maximize data ink ratio.

$$\text{data ink ratio} = \frac{\text{data ink}}{\text{total ink used in graphic}}$$



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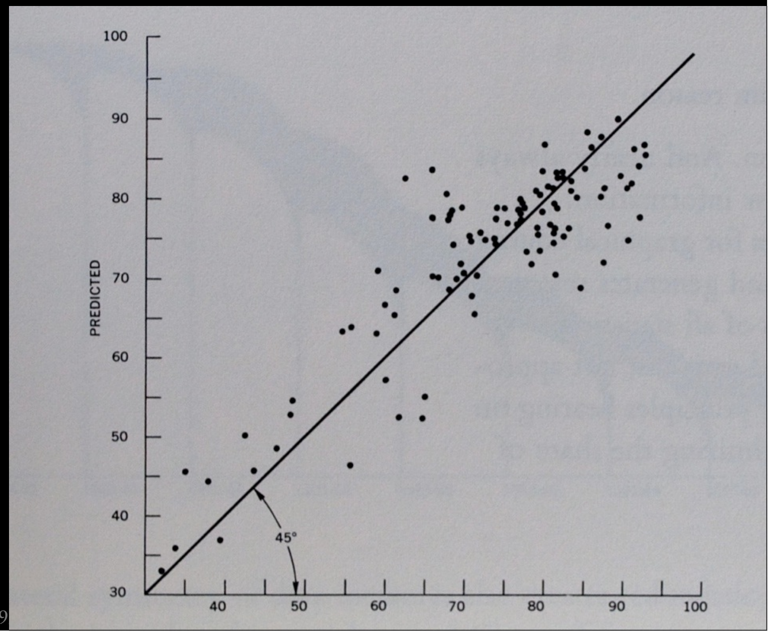
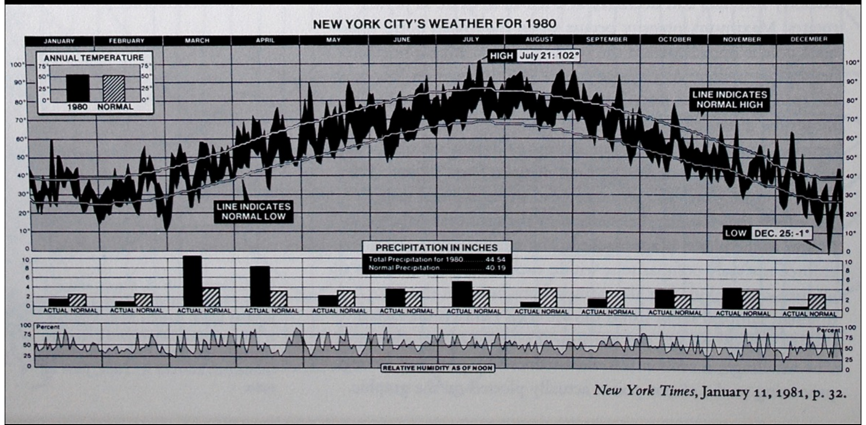


[Vol. 1, p. 9



New York Times, January 11, 1981, p. 32.

[Vol. 1, p. 30]

Above all else, show the data.

Maximize data ink ratio.

(Erase non-data ink.)

(Erase redundant data ink.)

Maximize data density.

$$\text{data density} = \frac{\text{number of data entries}}{\text{area of data graphic}}$$

"Maximize data density and the size of the data matrix, within reason."

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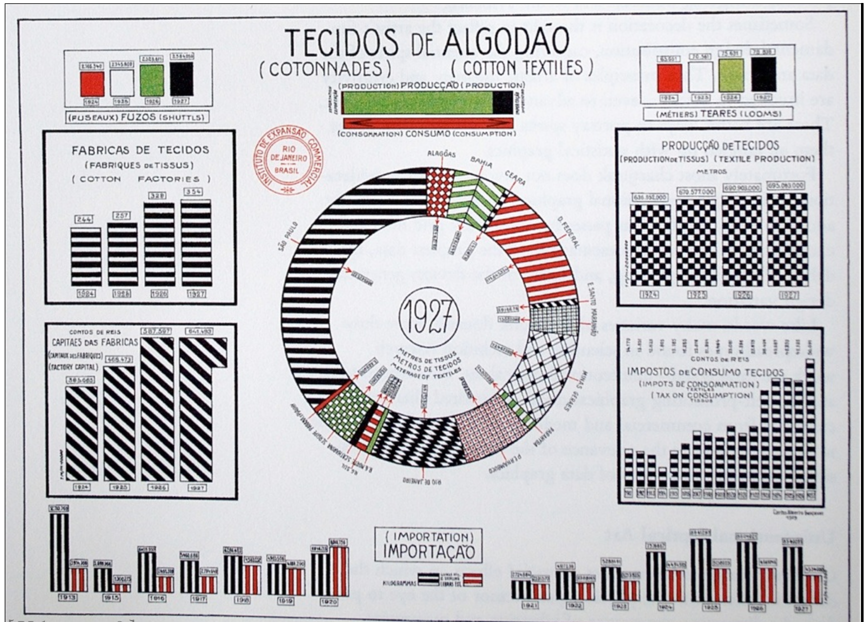

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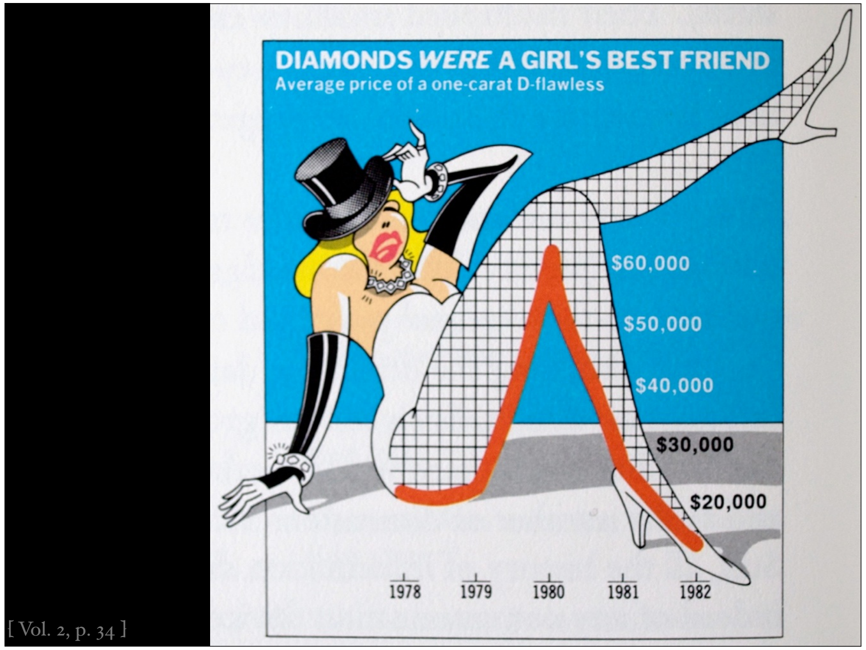
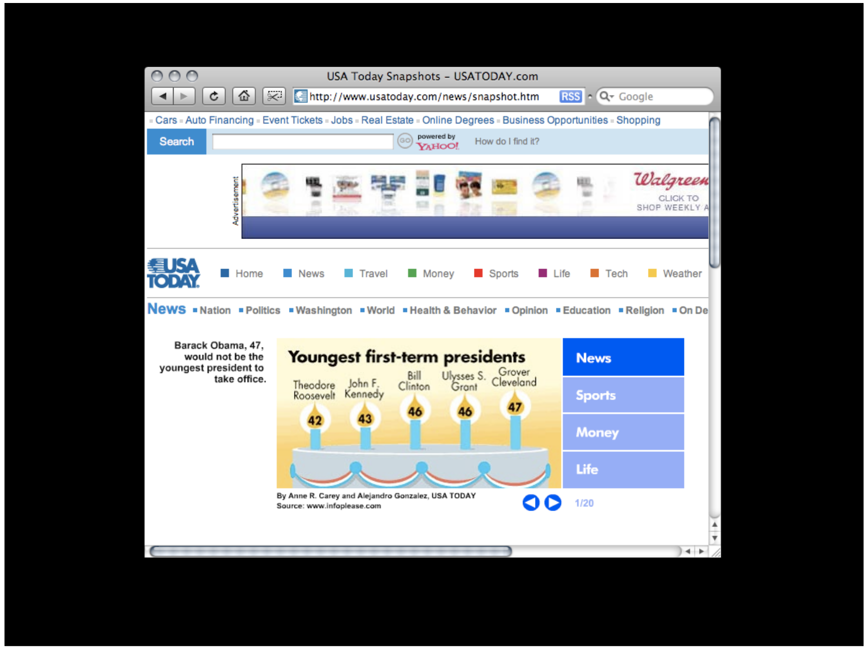
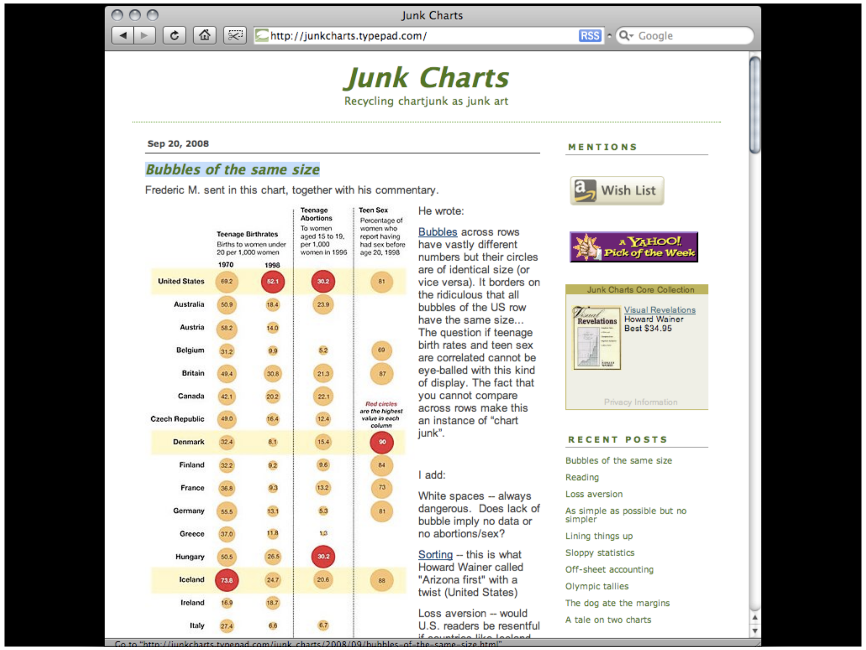


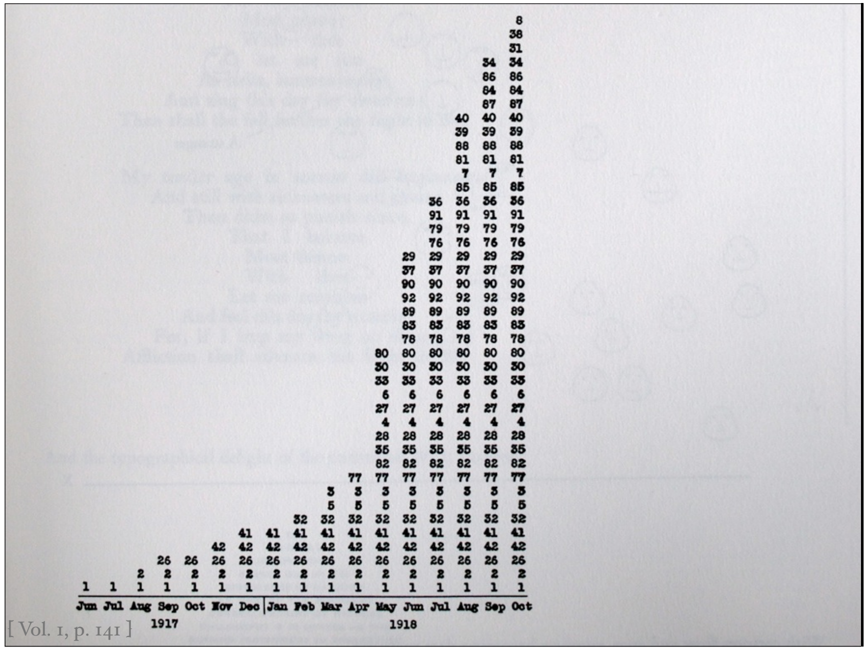




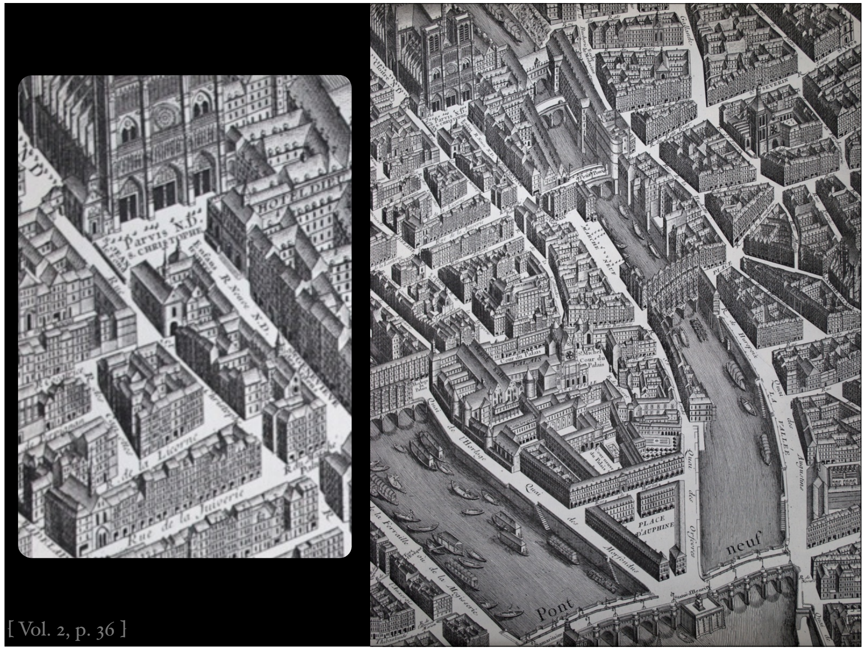
Use multifunctioning graphical elements.

(macro/micro readings)

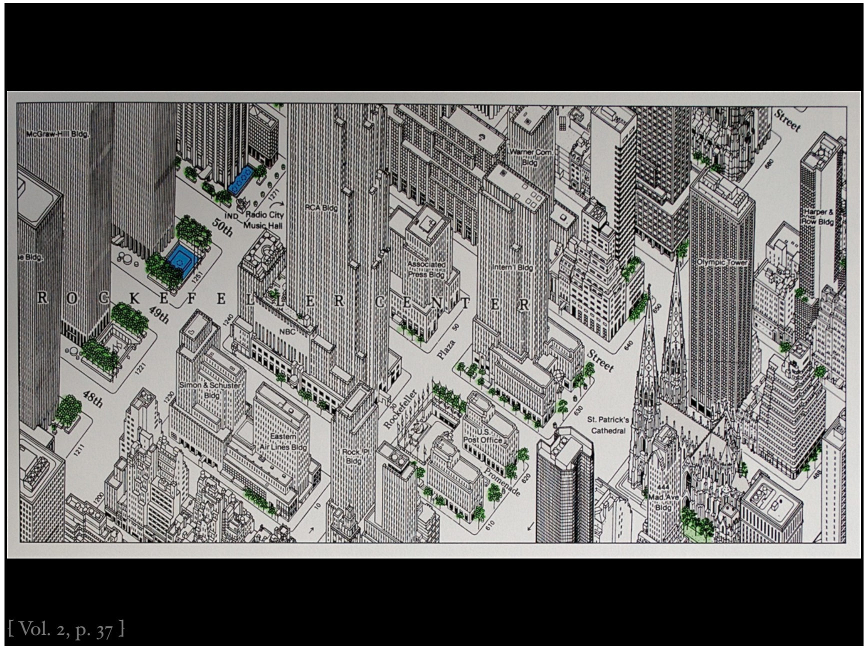
[Vol. 1, p. 140]



[Vol. 1, p. 141]



[Vol. 2, p. 36]



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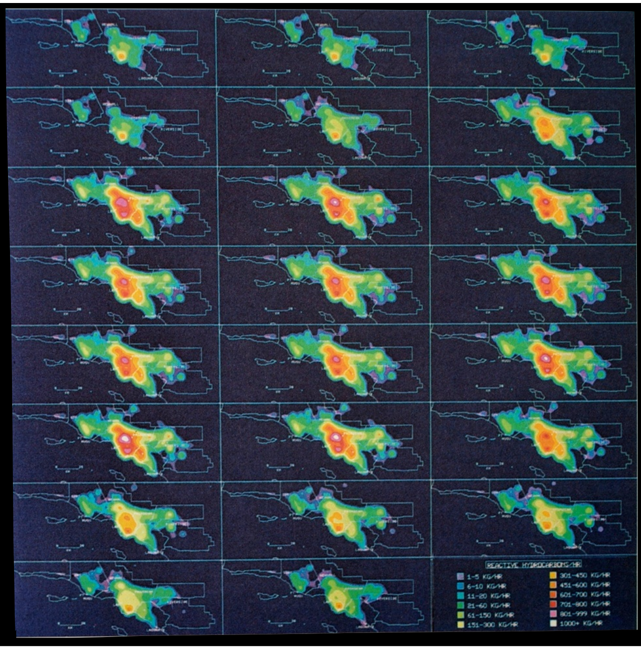
[Vol. 2, p. 42]

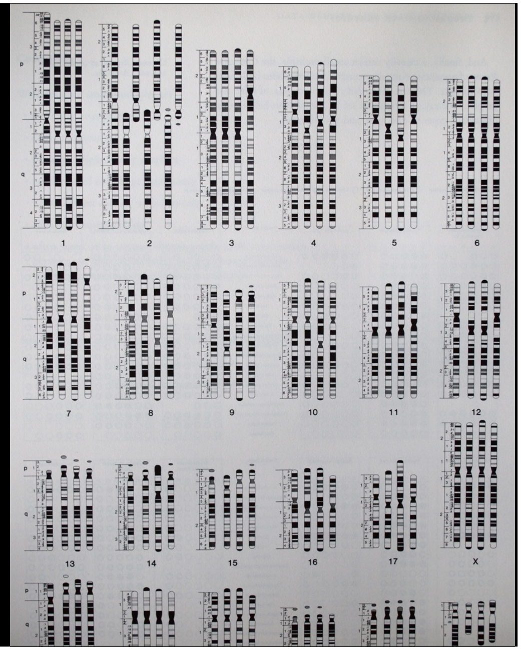
[Vol. 2, p. 43]

[Vol. 2, p. 44]

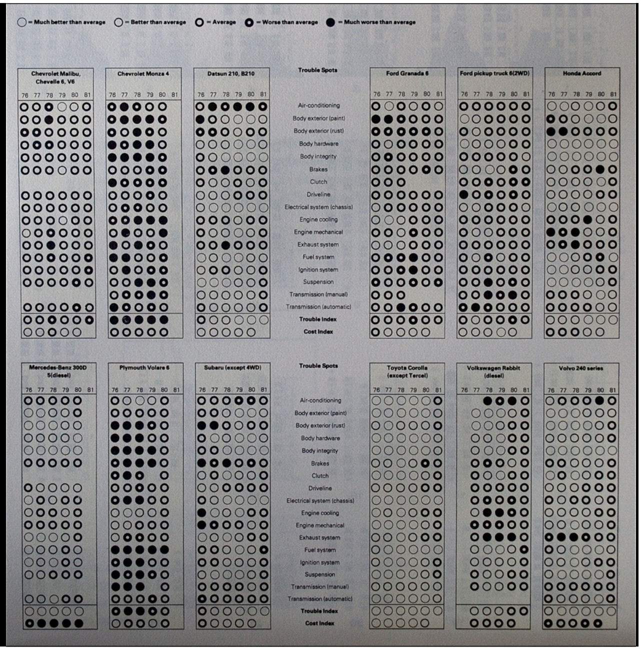
Use small multiples.



[Vol. 1, p. 170]



[Vol. 1, p. 173]



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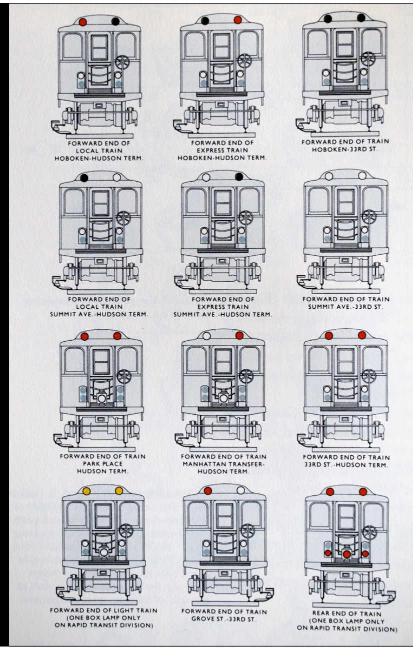

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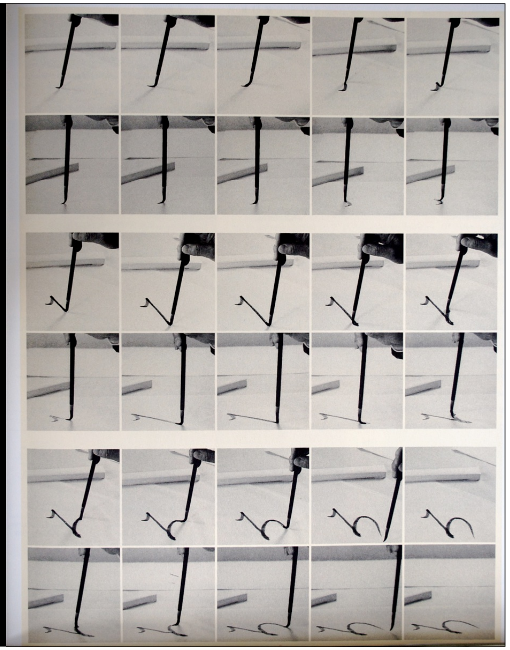
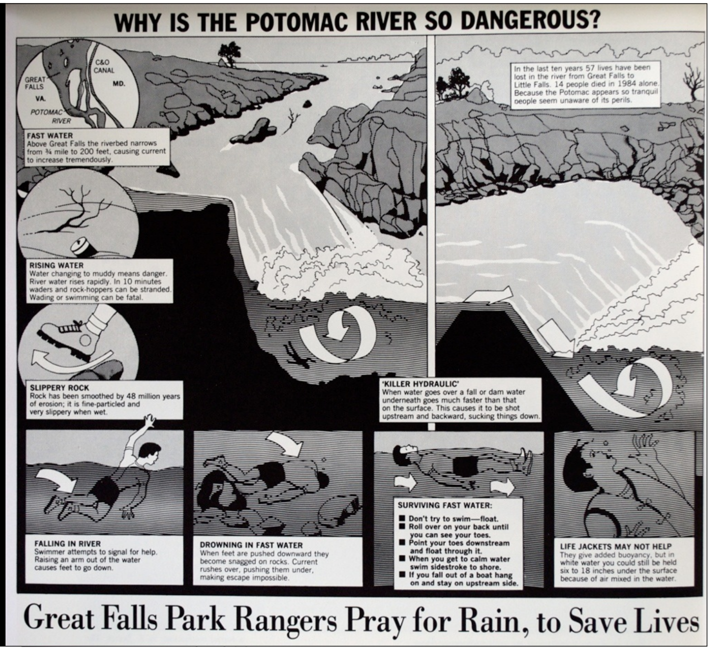


[Vol. 2, p. 69]

Show mechanism, process, dynamics, and causality.

(cause & effect are key)



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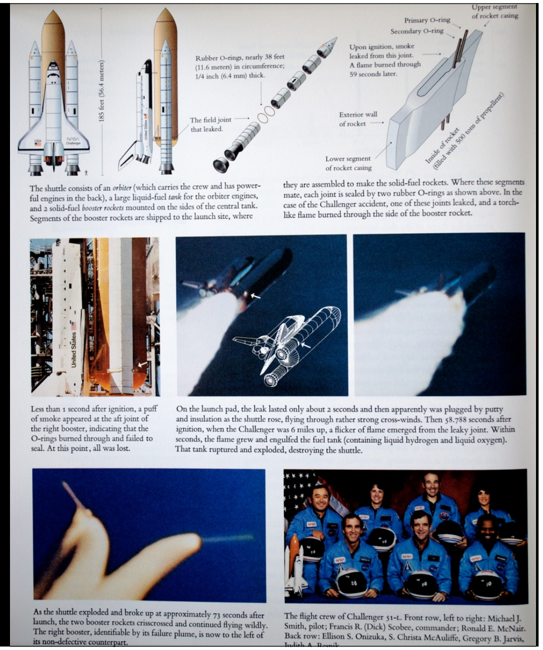

[Vol. 3, p. 38]

HISTORY OF O-RING DAMAGE ON SRM FIELD JOINTS

Oct 30, 1985

	SRM No.	Cross Sectional View: Erosion Depth (in.)	Perimeter Affected (deg)	Nominal Dia. (in.)	Top View: Length Of Max Erosion (in.)	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.

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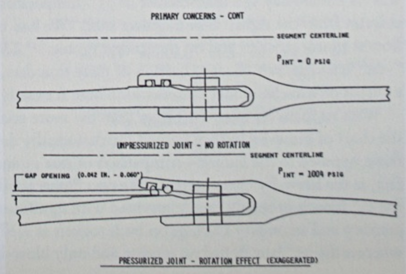
PRIMARY CONCERNS -

FIELD JOINT - HIGHEST CONCERN

- o EROSION PENETRATION OF PRIMARY SEAL REQUIRES RELIABLE SECONDARY SEAL FOR PRESSURE INTEGRITY
  - o IGNITION TRANSIENT - (0-600 MS)
    - o (0-170 MS) HIGH PROBABILITY OF RELIABLE SECONDARY SEAL
    - o (170-330 MS) REDUCED PROBABILITY OF RELIABLE SECONDARY SEAL
    - o (330-600 MS) HIGH PROBABILITY OF NO SECONDARY SEAL CAPABILITY
- o STEADY STATE - (600 MS - 2 MINUTES)
  - o IF EROSION PENETRATES PRIMARY O-RING SEAL - HIGH PROBABILITY OF NO SECONDARY SEAL CAPABILITY
    - o BENCH TESTING SHOWED O-RING NOT CAPABLE OF MAINTAINING CONTACT WITH METAL PARTS GAP OPENING RATE TO MEOP
    - o BENCH TESTING SHOWED CAPABILITY TO MAINTAIN O-RING CONTACT DURING INITIAL PHASE (0-170 MS) OF TRANSIENT

PRIMARY CONCERNS - CONT



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BLOW BY HISTORY

SRM-15 WORST BLOW-BY
- o 2 CASE JOINTS (80°), (110°) ARC
- o MUCH WORSE VISUALLY THAN SRM-22

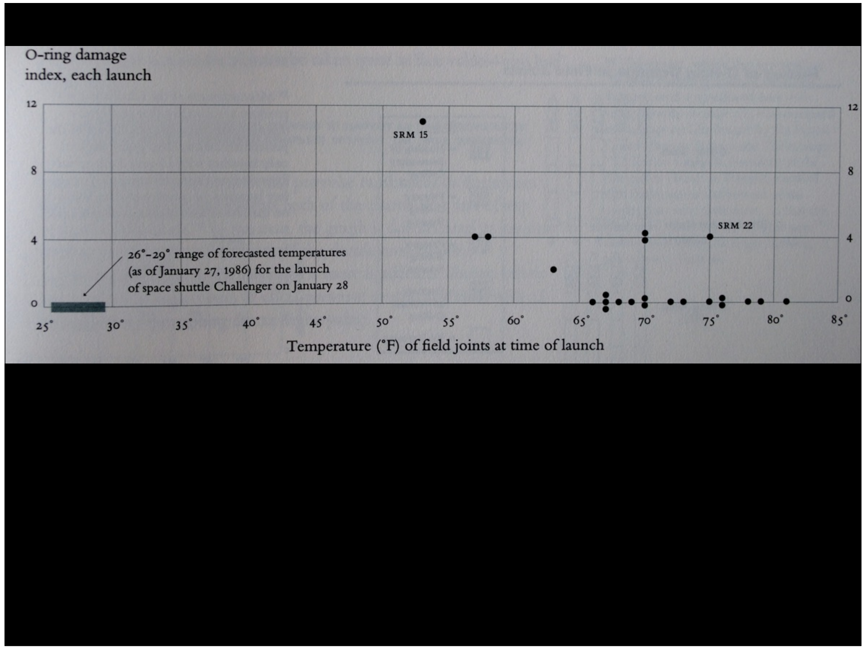
SRM 22 BLOW-BY
- o 2 CASE JOINTS (30-40°)

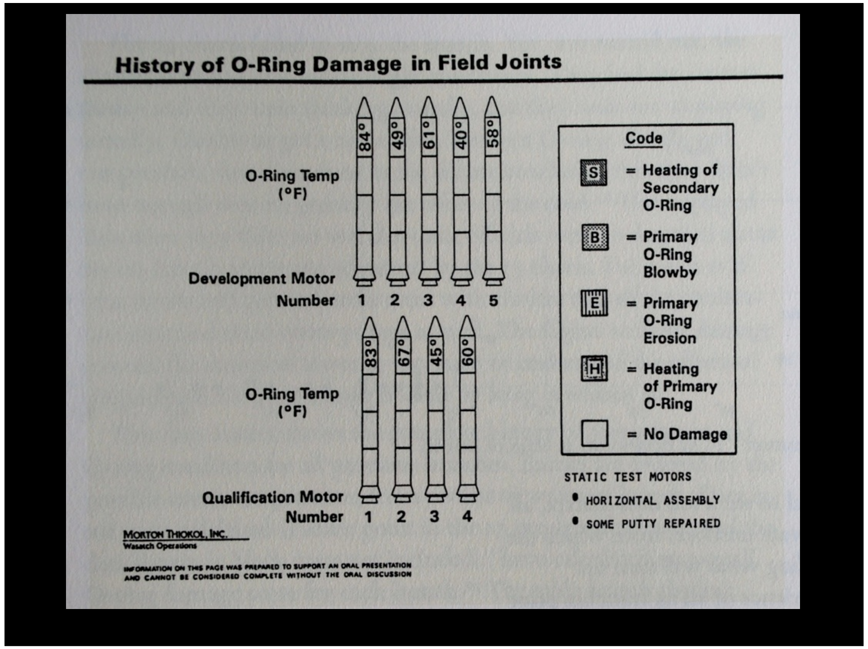
SRM-13A, 15, 16A, 18, 23A 24A
- o NOZZLE BLOW-BY

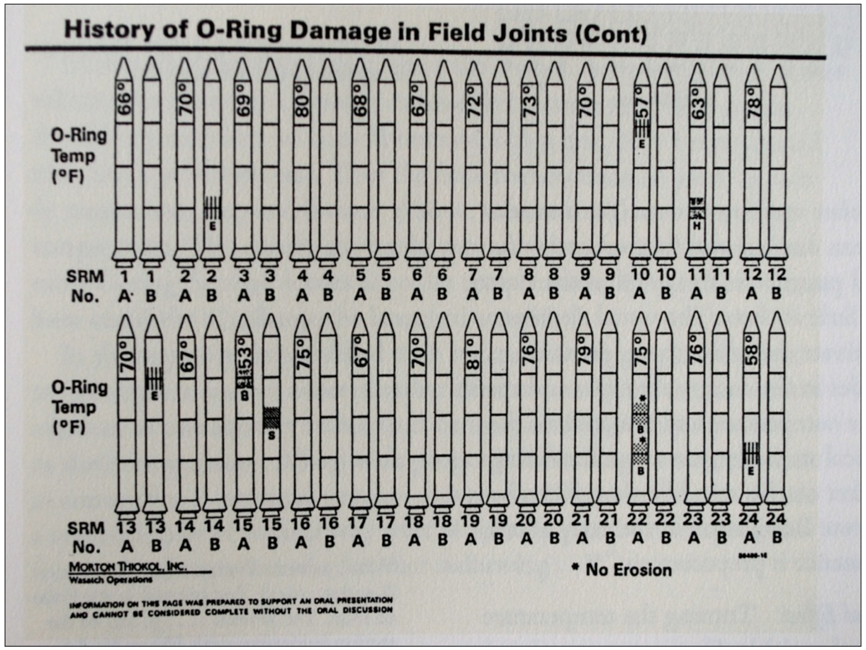
HISTORY OF O-RING TEMPERATURES (DEGREES - F)

MOTOR	MBT	AMB	O-RING	WIND
DM-4	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

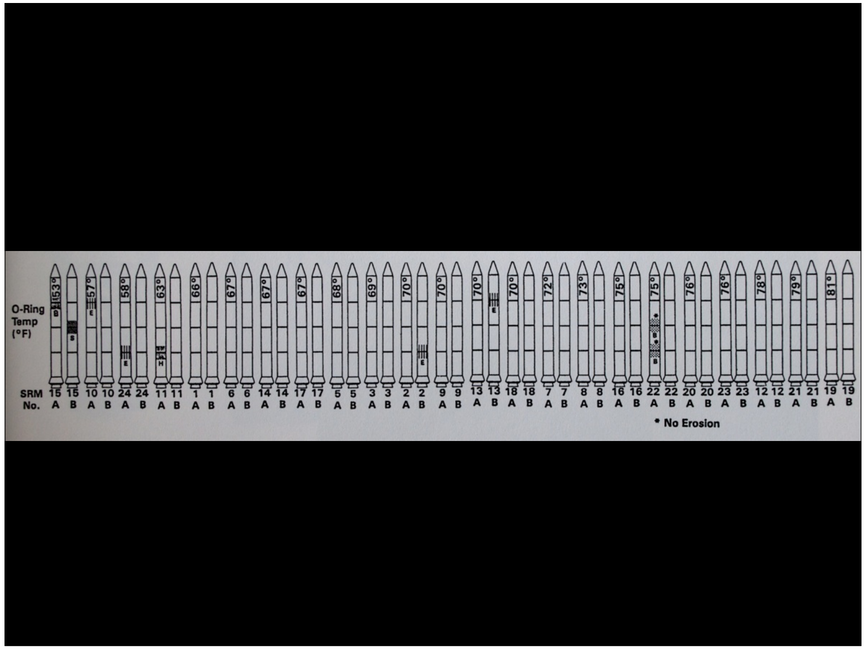
Flight	Date	Temperature °F	Erosion incidents	Blow-by incidents	Damage index	Comments
51-C	01.24.85	53°	3	2	11	Most erosion any flight; blow-by; back-up rings heated.
41-B	02.03.84	57°	1		4	Deep, extensive erosion.
61-C	01.12.86	58°	1		4	O-ring erosion on launch two weeks before Challenger.
41-C	04.06.84	63°	1		2	O-rings showed signs of heating, but no damage.
1	04.12.81	66°			0	Coolest (66°) launch without O-ring problems.
6	04.04.83	67°			0	
51-A	11.08.84	67°			0	
51-D	04.12.85	67°			0	
5	11.11.82	68°			0	
3	03.22.82	69°			0	
2	11.12.81	70°	1		4	Extent of erosion not fully known.
9	11.28.83	70°			0	
41-D	08.30.84	70°	1		4	
51-G	06.17.85	70°			0	
7	06.18.83	72°			0	
8	08.30.83	73°			0	
51-B	04.29.85	75°			0	
61-A	10.30.85	75°		2	4	No erosion. Soot found behind two primary O-rings.
51-I	08.27.85	76°			0	
61-B	11.26.85	76°			0	
41-G	10.05.84	78°			0	
51-J	10.03.85	79°			0	
4	06.27.82	80°			?	O-ring condition unknown; rocket casing lost at sea.
51-F	07.29.85	81°			0	

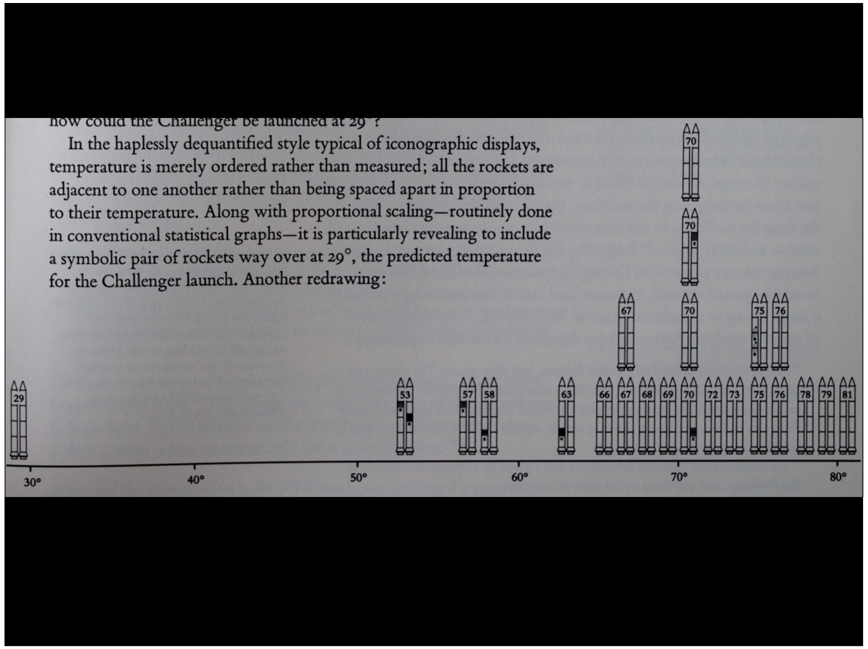




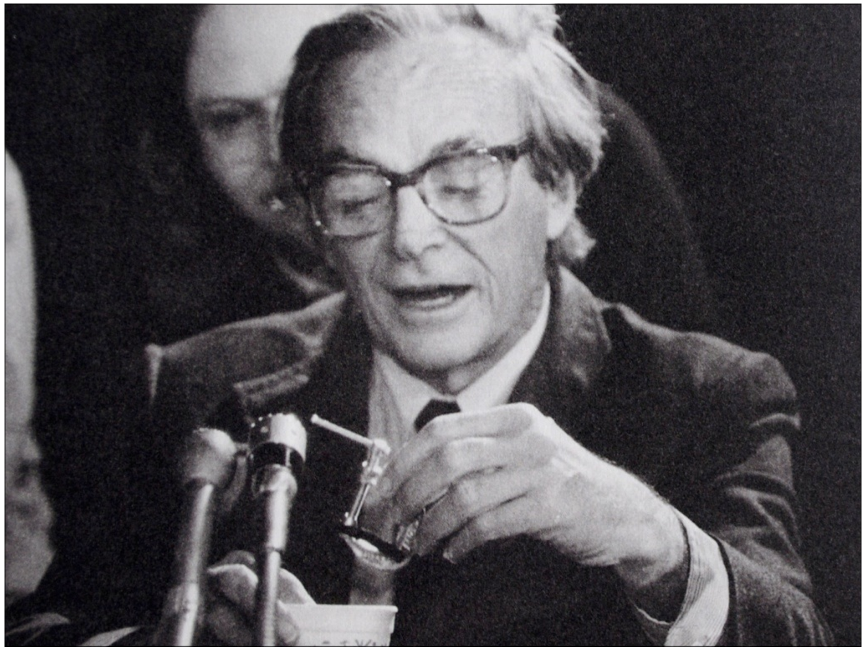


INFORMATION ON THIS PAGE WAS PREPARED TO SUPPORT AN ORAL PRESENTATION
AND CANNOT BE CONSIDERED COMPLETE WITHOUT THE ORAL DISCUSSION

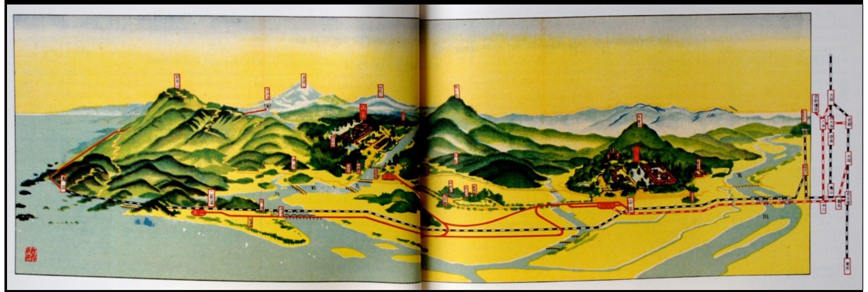



how could the Challenger be launched at 29°?

In the haplessly dequantified style typical of iconographic displays, temperature is merely ordered rather than measured; all the rockets are adjacent to one another rather than being spaced apart in proportion to their temperature. Along with proportional scaling—routinely done in conventional statistical graphs—it is particularly revealing to include a symbolic pair of rockets way over at 29°, the predicted temperature for the Challenger launch. Another redrawing:



Escape flatland.



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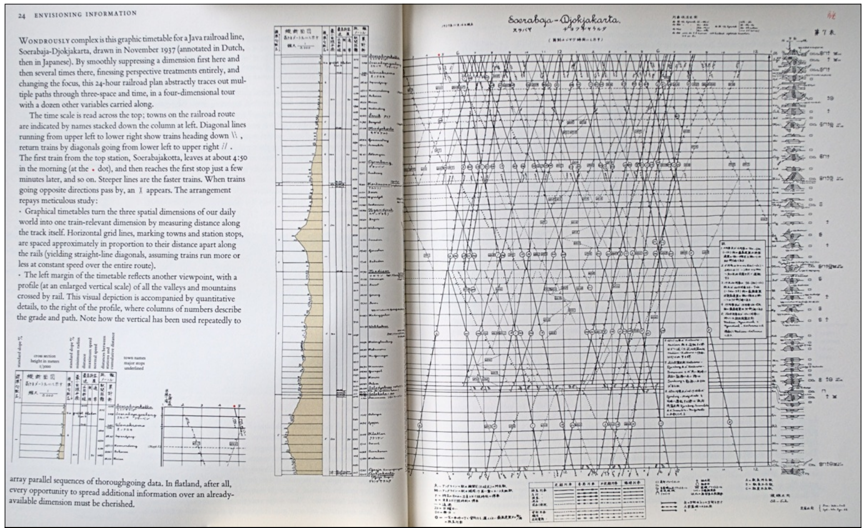


24 ENVISIONING INFORMATION

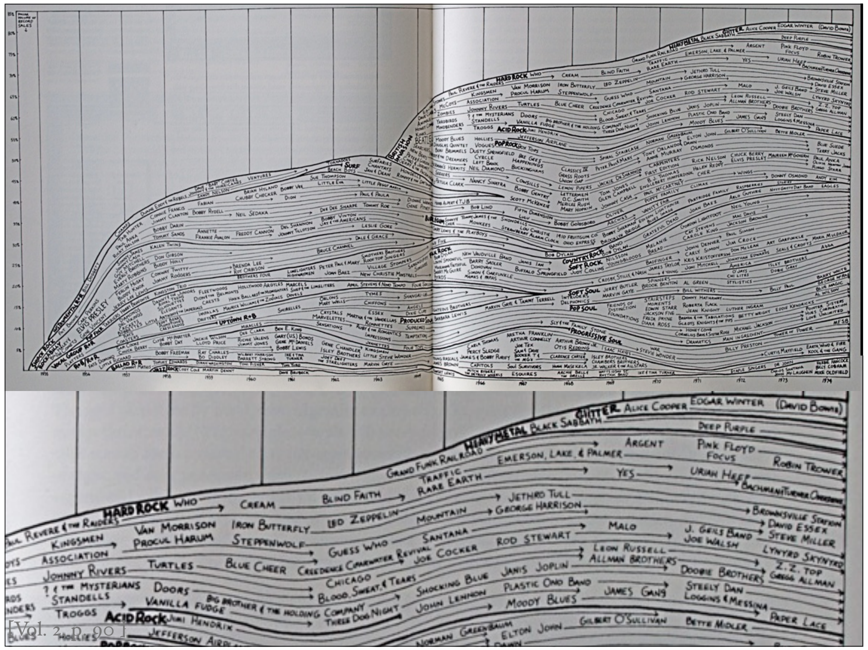
WONDROUSLY complex is this graphic timetable for a Java railroad line, Soerabaja-Djokjakarta, drawn in November 1937 (annotated in Dutch, then in Japanese). By smoothly suppressing a dimension first here and then several times there, finessing perspective treatments entirely, and changing the focus, this 24-hour railroad plan abstractly traces out multiple paths through three-space and time, in a four-dimensional tour with a dozen other variables carried along.

The time scale is read across the top; towns on the railroad route are indicated by names stacked down the column at left. Diagonal lines running from upper left to lower right show trains heading down \\ , return trains by diagonals going from lower left to upper right // . The first train from the top station, Soerabajakotta, leaves at about 4:50 in the morning (at the • dot), and then reaches the first stop just a few minutes later, and so on. Steeper lines are the faster trains. When trains going opposite directions pass by, an X appears. The arrangement repays meticulous study:

- Graphical timetables turn the three spatial dimensions of our daily world into one train-relevant dimension by measuring distance along the track itself. Horizontal grid lines, marking towns and station stops, are spaced approximately in proportion to their distance apart along the rails (yielding straight-line diagonals, assuming trains run more or less at constant speed over the entire route).
- The left margin of the timetable reflects another viewpoint, with a profile (at an enlarged vertical scale) of all the valleys and mountains crossed by rail. This visual depiction is accompanied by quantitative details, to the right of the profile, where columns of numbers describe the grade and path. Note how the vertical has been used repeatedly to

array parallel sequences of thoroughgoing data. In flatland, after all, every opportunity to spread additional information over an already-available dimension must be cherished.

[Vol. 2, p. 24]



[Vol. 2, p. 90]

Use layering & separation.

(1 + 1 = 3 or more)

Here I have 2 equal strips of cardboard (1″ x 6″)

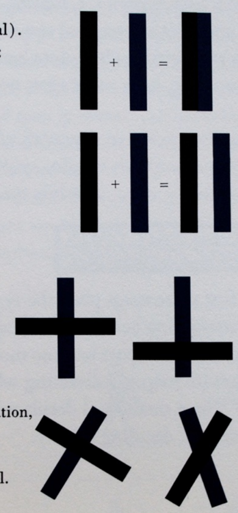
Here is one (vertical), here another (also vertical).
Seeing one strip plus one strip, we count 2 strips:
1 + 1 = 2.

We recognize the equal width of the strips.
Now, 1 width + 1 width (strips touching)
equals 2 widths: 1 + 1 = 2.

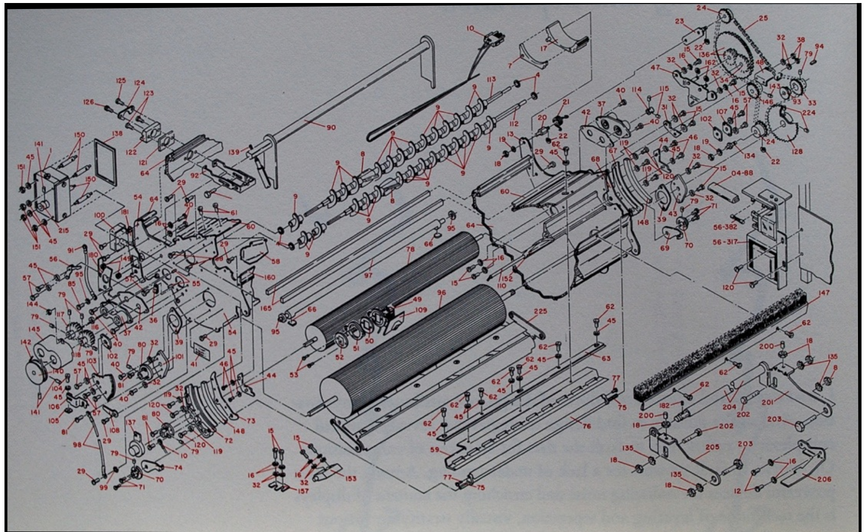
But now, separating them (both remain vertical)
by 1 width — we count 3 widths
(one of them negative): 1 + 1 = 3.

Of the 2 vertical strips,
one crosses the other horizontally
in their centers.
Result: 2 lines form a crossing
thus producing 4 arms, as 4 extensions,
to be read inward as well as outward.
We also see 4 rectangles, and with some imagination,
4 triangles, 4 squares.
By shifting centers and angles,
arms and the in-between figures become unequal.

All together: one line plus one line
results in many meanings — *Quod erat demonstrandum.*



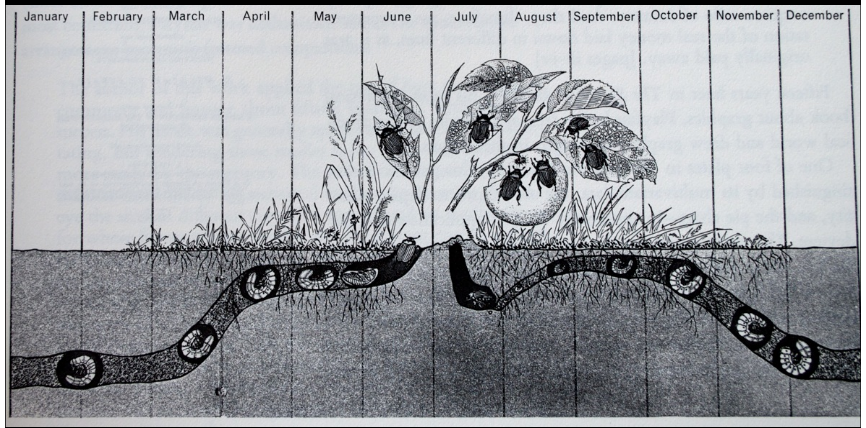
[Vol. 2, p. 61]



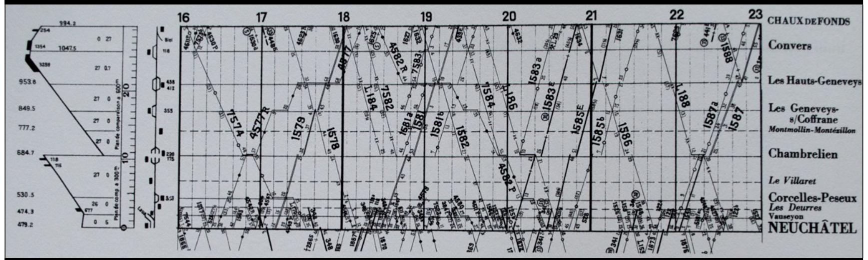
IBM Series III Copier/Duplicator, Adjustment Parts Manual (Boulder, Colorado, 1976), p. 101. Drawn by Gary E. Graham.

[Vol. 2, p. 54]

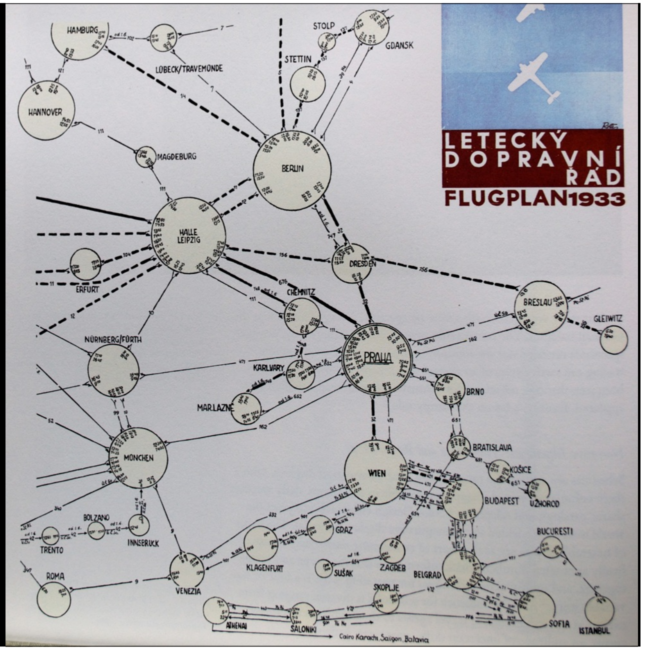
Utilize narratives of space & time.



[Vol. 1, p. 43; Vol. 2, p. 110]

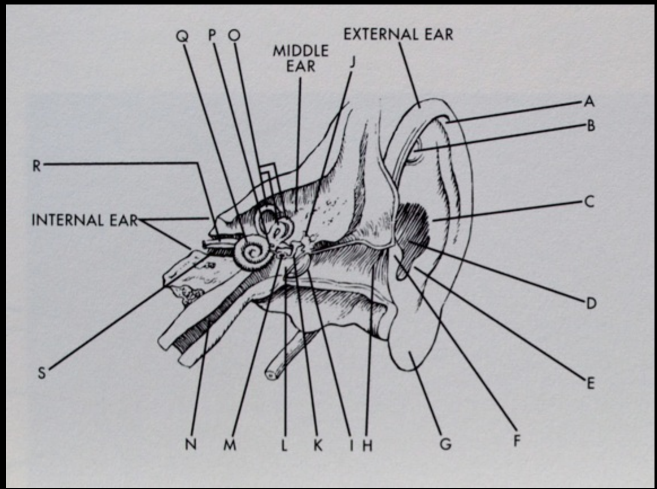


[Vol. 2, p. 102]

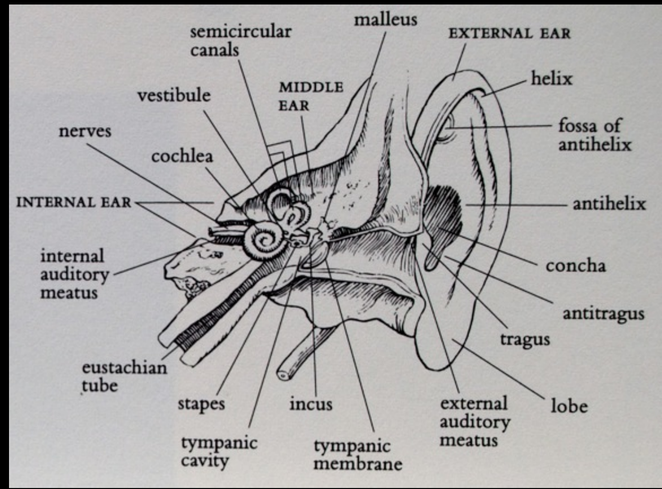


[Vol. 2, p. 103]

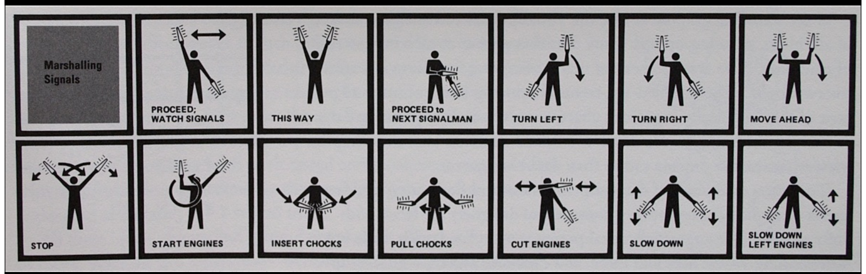
Content is king.



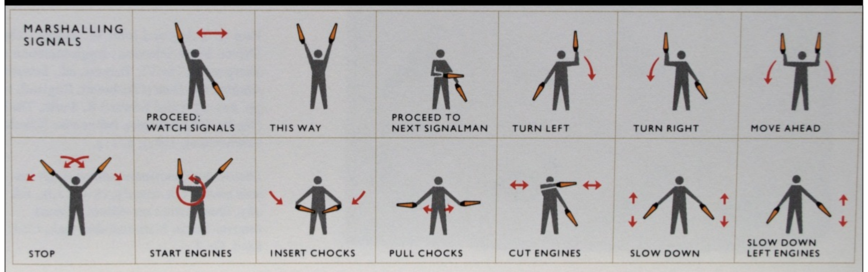
[Vol. 3, p. 74]



[Vol. 3, p. 74]



[Vol. 2, p. 63]

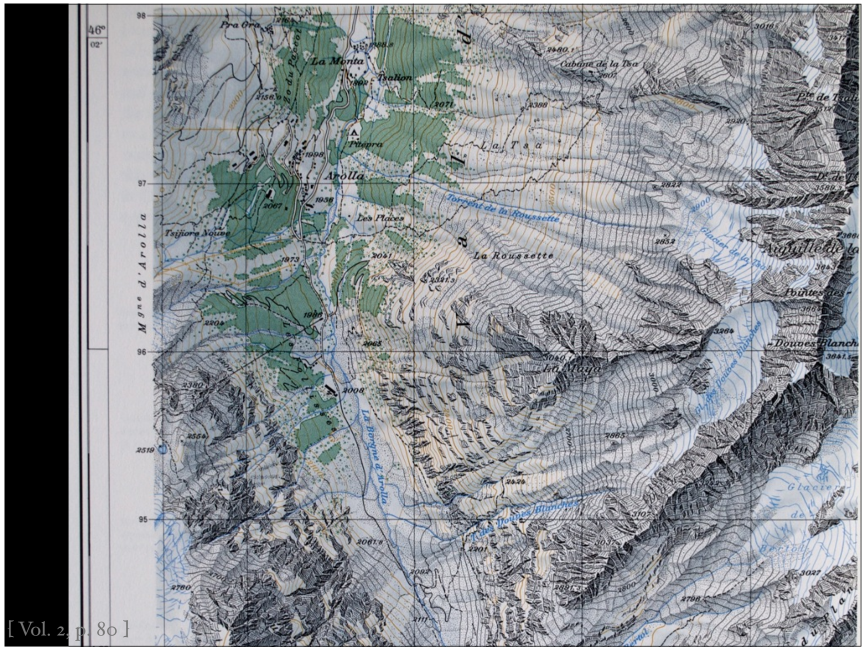


[Vol. 2, p. 63]

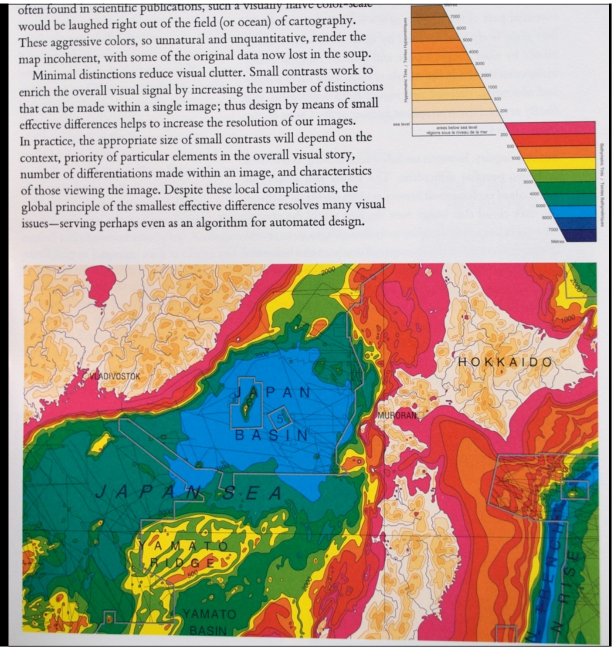
"The often scant benefits derived from coloring data indicate that even putting a good color in a good place is a complex matter. Indeed, so difficult and subtle that avoiding catastrophe becomes the first principle in bringing color to information: **Above all, do no harm.**"

Use color to:

- label
- measure
- represent or imitate reality
- enliven or decorate



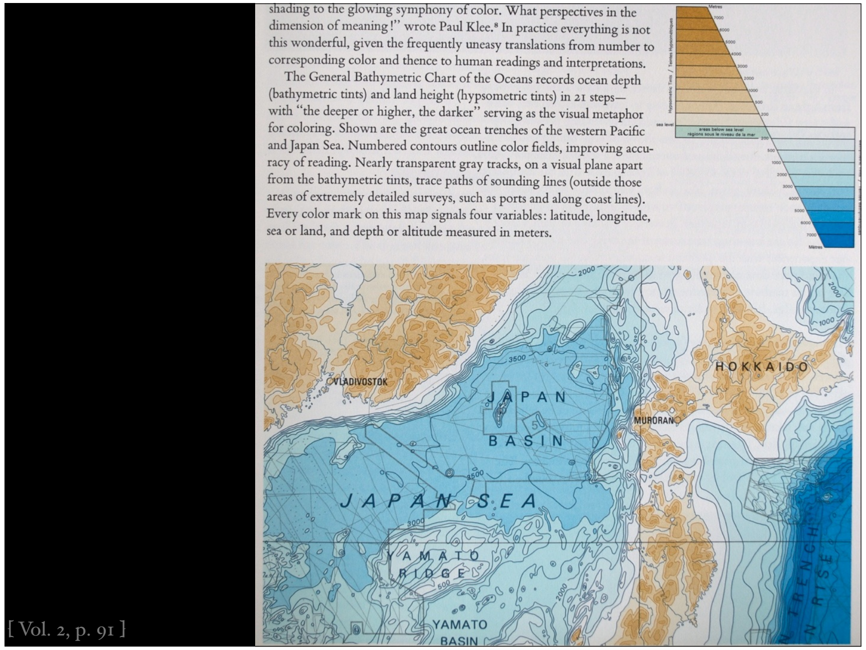
[Vol. 2, p. 80]

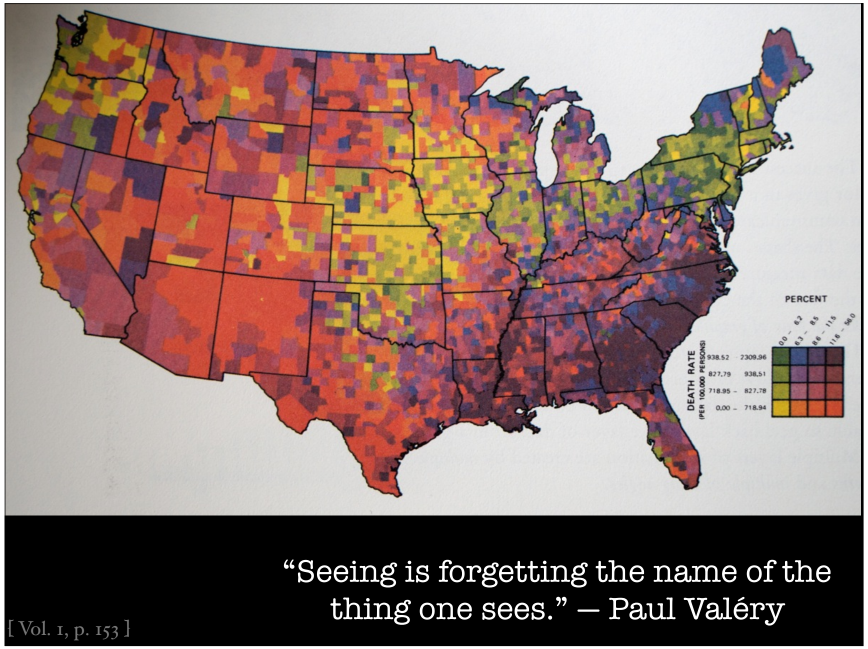


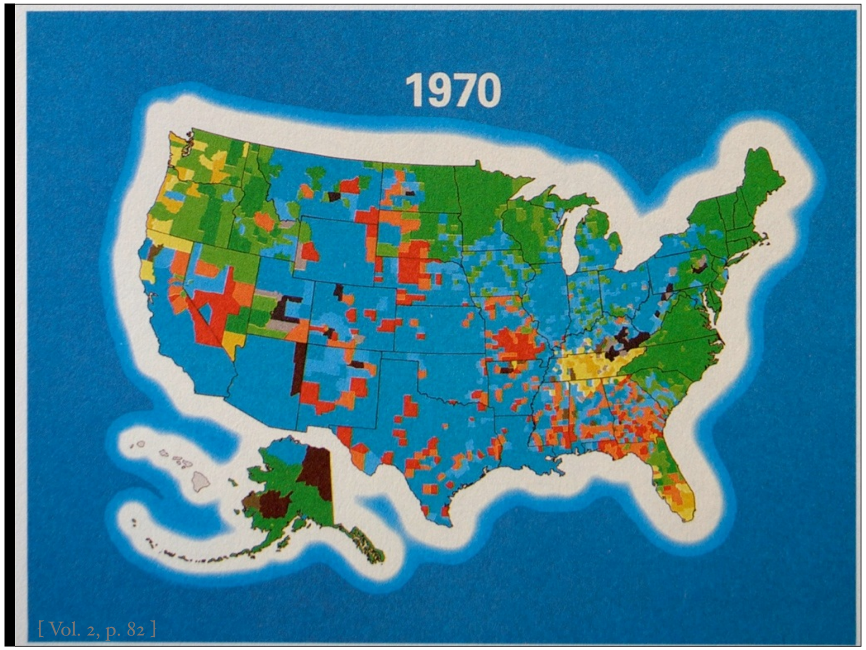
often found in scientific publications, such a visually naive color-scale would be laughed right out of the field (or ocean) of cartography. These aggressive colors, so unnatural and unquantitative, render the map incoherent, with some of the original data now lost in the soup.

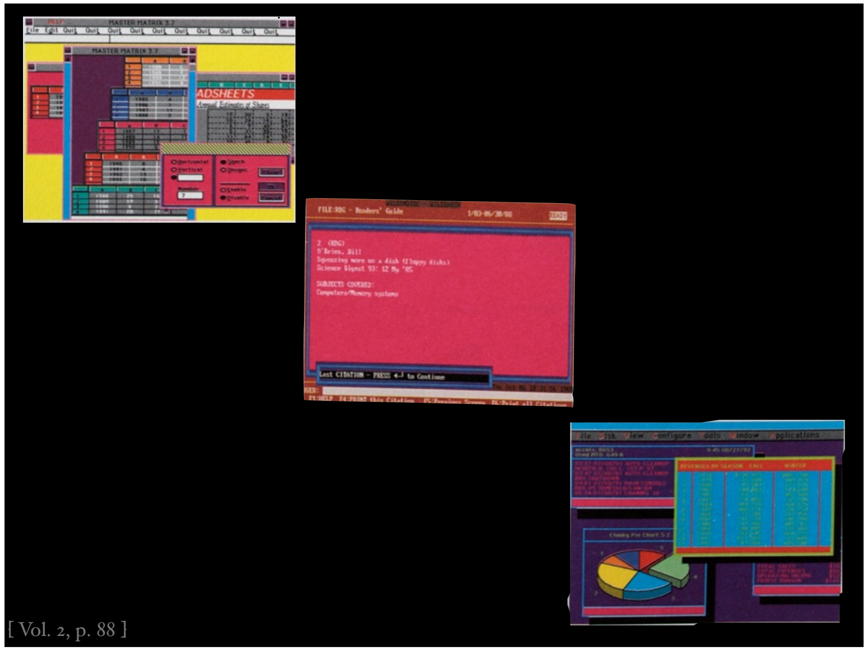
Minimal distinctions reduce visual clutter. Small contrasts work to enrich the overall visual signal by increasing the number of distinctions that can be made within a single image; thus design by means of small effective differences helps to increase the resolution of our images. In practice, the appropriate size of small contrasts will depend on the context, priority of particular elements in the overall visual story, number of differentiations made within an image, and characteristics of those viewing the image. Despite these local complications, the global principle of the smallest effective difference resolves many visual issues—serving perhaps even as an algorithm for automated design.

[Vol. 3, p. 77]


shading to the glowing symphony of color. What perspectives in the dimension of meaning!" wrote Paul Klee.[8] In practice everything is not this wonderful, given the frequently uneasy translations from number to corresponding color and thence to human readings and interpretations.
The General Bathymetric Chart of the Oceans records ocean depth (bathymetric tints) and land height (hypsometric tints) in 21 steps—with "the deeper or higher, the darker" serving as the visual metaphor for coloring. Shown are the great ocean trenches of the western Pacific and Japan Sea. Numbered contours outline color fields, improving accuracy of reading. Nearly transparent gray tracks, on a visual plane apart from the bathymetric tints, trace paths of sounding lines (outside those areas of extremely detailed surveys, such as ports and along coast lines). Every color mark on this map signals four variables: latitude, longitude, sea or land, and depth or altitude measured in meters.
VLADIVOSTOK
JAPAN BASIN
HOKKAIDO
MURORAN
JAPAN SEA
YAMATO RIDGE
YAMATO BASIN
[Vol. 2, p. 91]


PERCENT
DEATH RATE (PER 100,000 PERSONS)
[Vol. 1, p. 153]
"Seeing is forgetting the name of the thing one sees." — Paul Valéry


1970
[Vol. 2, p. 82]


[Vol. 2, p. 88]

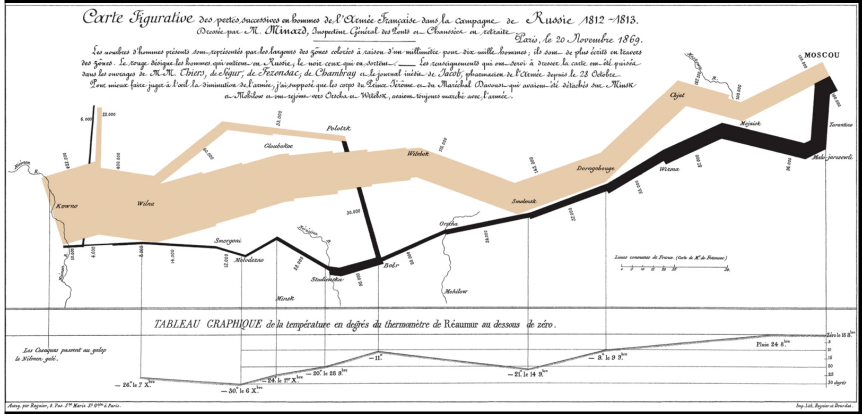
Attractive displays of statistical info

* have a properly chosen format and design
* use words, numbers and drawing together
* reflect a balance, a proportion, a sense of relevant scale
* display an accessible complexity of detail
* often have a narrative quality, a story to tell about the data
* are drawn in a professional manner, with the technical details of production done with care
* avoid content-free decoration, including chartjunk

Information Overload

"Clutter and confusion are failures of design, not attributes of information."

[Vol. 2, p. 51]



[Vol. 1, p. 41]

Graphical Displays Should

* Show the data
* Induce the viewer to think about substance rather than about methodology, graphic design the technology of graphic production, or something else
* Avoid distorting what the data have to say
* Present many numbers in a small space
* Make large data sets coherent
* Encourage the eye to compare different pieces of data

Graphical Displays Should

* Reveal the data at several levels of detail, from a broad overview to the fine structure
* Serve a reasonably clear purpose: description, exploration, tabulation, or decoration
* Be closely integrated with statistical and verbal descriptions of a data set