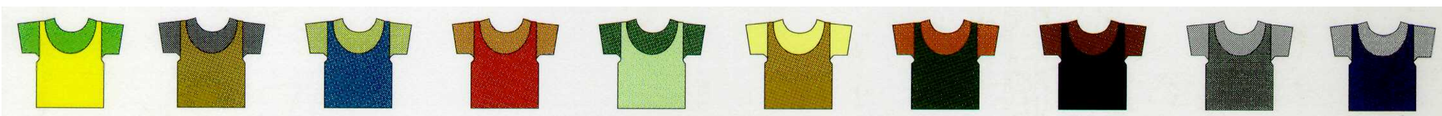
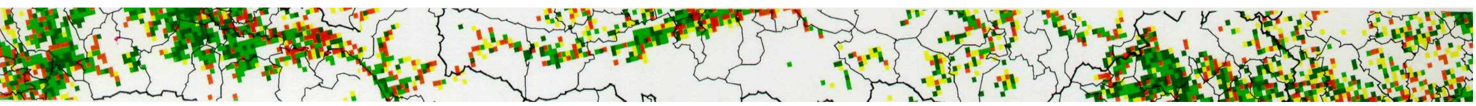
Edward R. Tufte

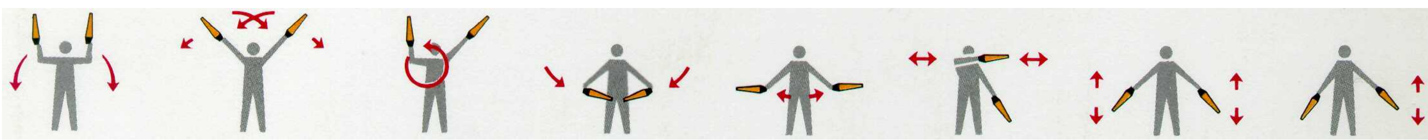
Envisioning Information



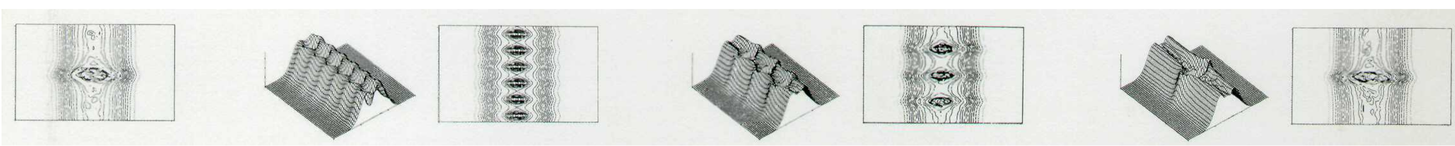
ESCAPING FLATLAND



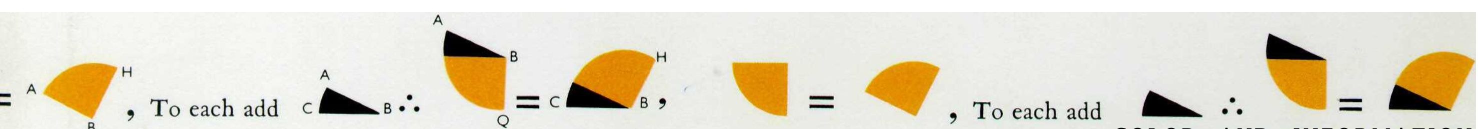
MICRO/MACRO READINGS



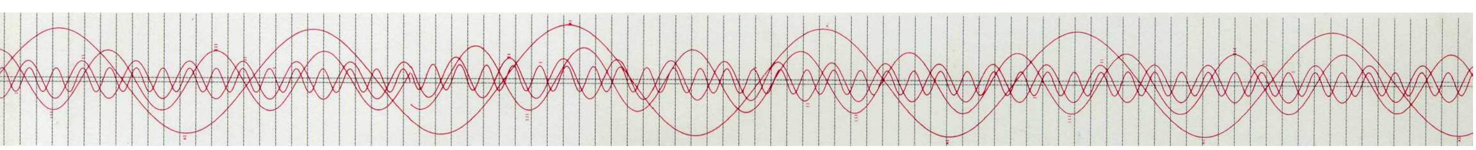
LAYERING AND SEPARATION



SMALL MULTIPLES



COLOR AND INFORMATION

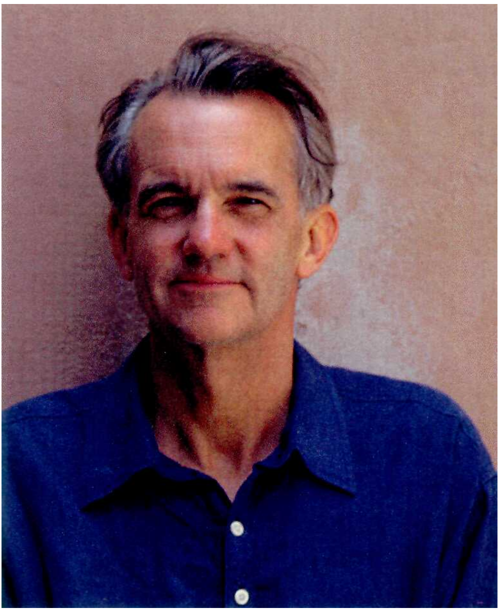


NARRATIVES OF SPACE AND TIME

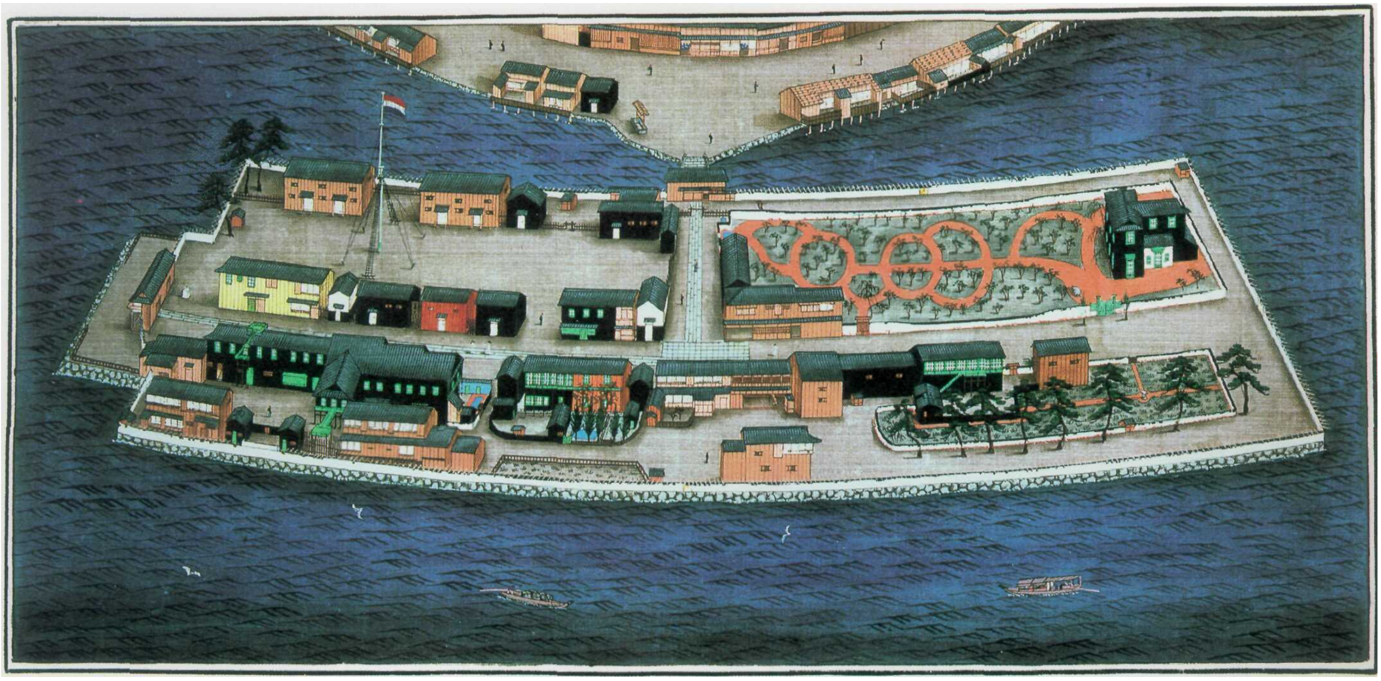
Edward Tufte is a professor at Yale University, where he teaches courses in statistical evidence and information design. His books include *Visual Explanations: Images and Quantities, Evidence and Narrative, Envisioning Information, The Visual Display of Quantitative Information, Political Control of the Economy, Data Analysis for Politics and Policy,* and *Size and Democracy* (with Robert A. Dahl).

He is a fellow of the American Statistical Association, the American Academy of Arts and Sciences, the Guggenheim Foundation, and the Center for Advanced Study in the Behavioral Sciences. He has received honorary doctorates from The Cooper Union and Connecticut College, the Phi Beta Kappa Award in Science, and the Joseph Rigo Award for contributions to software documentation from the Association for Computing Machinery.

Envisioning Information has received 14 awards for content and design, including the Phi Beta Kappa Award in Science and "Best Graphic Design of the Year" from *International Design.*



photograph by Inge Druckrey, Rome 1997



Two paintings on silk depicting Dejima Island, a view from the Bay (top), a view from Nagasaki (bottom), circa 1860.

Edward R. Tufte

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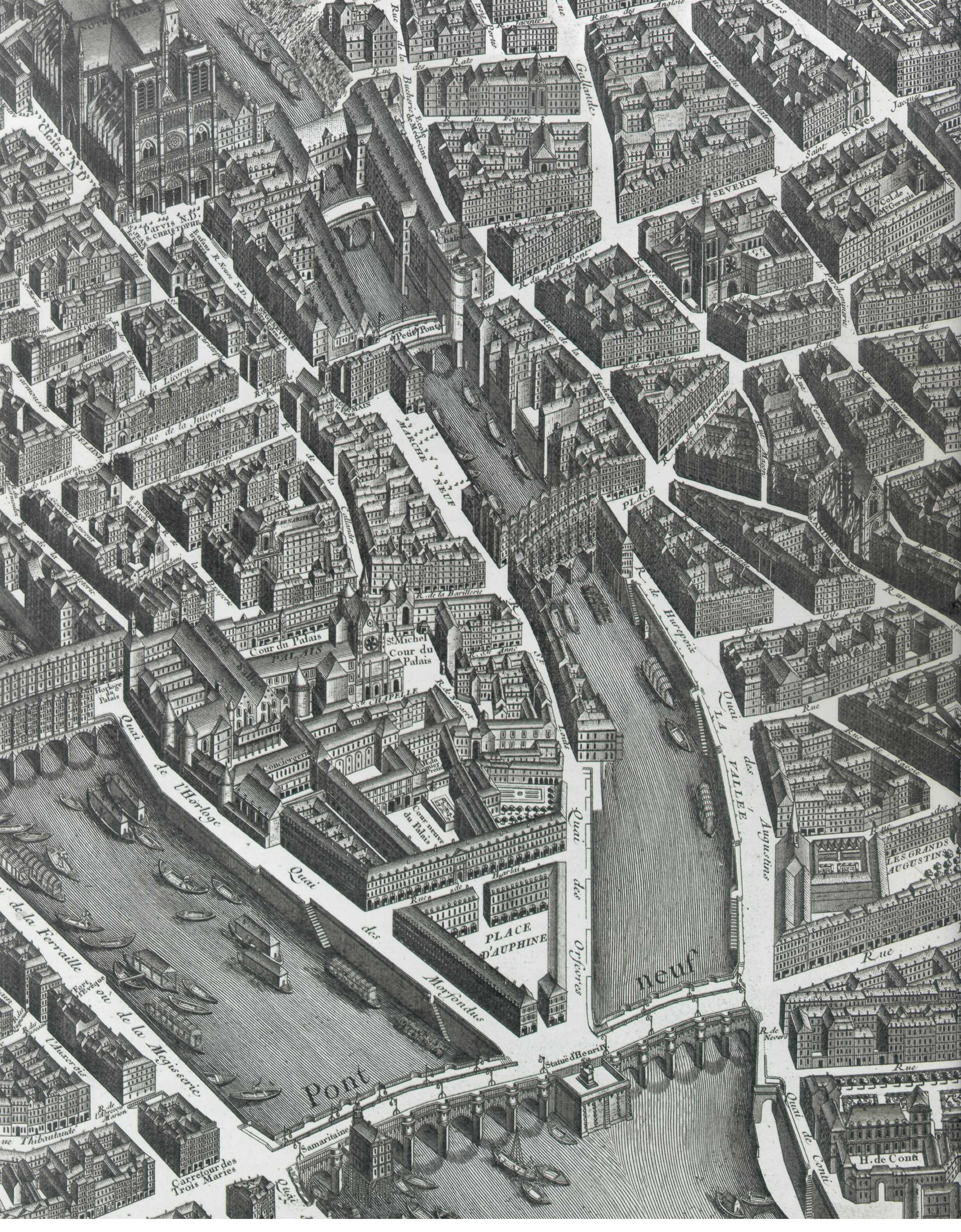
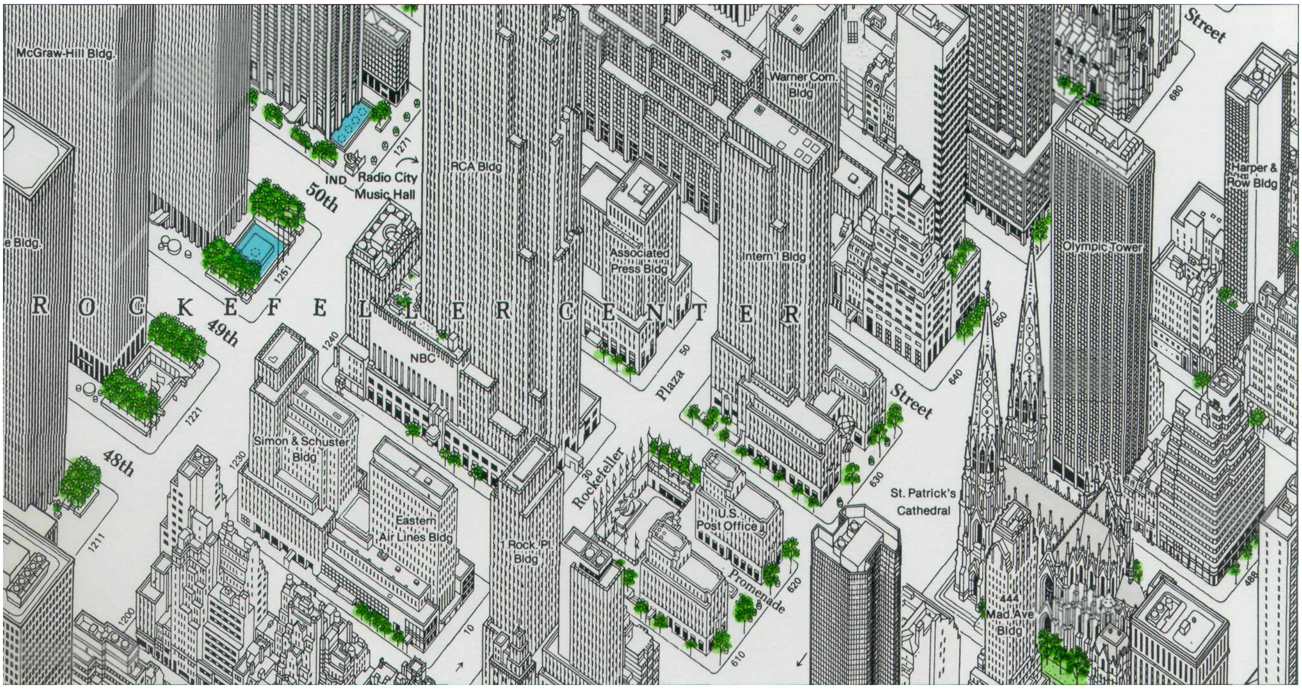

Parvis N.D.
Rue de la Juiverie
Rue de la Lanterne
Rue de la Licorne
MARCHÉ NEUF
Petit Pont
S.T SEVERIN
Rue de la Huchette
R. du P.tit Pont
Galande
Rue des Rats
Rue du Foüarre
Rue de la Bucherie
Ecole de Medecine
PLACE
R. de Hurepoix
Cour du PALAIS
S.t Michel
Cour du Palais
LA S.te CHAPELLE
Horloge du Palais
Quai de l'Horloge
Conciergerie
Cour neuve du Palais
Quai des Morfondus
Quai des Orfevres
PLACE DAUPHINE
Quai des Augustins
LA VALLÉE
LES GRANDS AUGUSTINS
Pont neuf
Statue d'Henri IV
Samaritaine
R. de Nevers
Quai de Conti
H. de Conti
Rue de la Ferraille ou de la Megisserie
Fort l'Eveque
Carrefour des Trois Maries
Rue Thibautaude
Rue S.t Jacques
Rue des Anglois
Rue Saint Severin
Rue de la Harpe
Rue des Arcs
Rue de la Barillerie
Rue de Harlai
Rue de Nazaret
Rue de Savoie

2 Micro / Macro Readings



For 20 years Constantine Anderson refined this precise axonometric projection of midtown New York (shown here are Rockefeller Center environs), following the tradition of the classic 1739 Bretez-Turgot *Plan de Paris* (at left, the area around Pont Neuf and Notre Dame, from the 11th of 20 sheets). The Manhattan map embraces such fine points as individual windows, subway stations and bus shelters, telephone booths, building canopies, trees, and sidewalk planters. And the typography is persistently thorough; the entire map (60 by 92 centimeters, or 24 by 36 inches) reports 1,686 names of buildings, stores, and parks along with 657 specific street addresses—for a map, an abundant typographic density of 3 characters per square centimeter (20 per square inch). The only major concession to paper flatland is widening of the map's streets to reduce masking of some buildings by others.

This fine texture of exquisite detail leads to personal micro-readings, individual stories about the data: shops visited, hotels stayed at, walks taken, office windows at a floor worked on—all in the extended context of an entire building, street, and neighborhood.[1] Detail cumulates into larger coherent structures; those thousands of tiny windows, when seen at a distance, gray into surfaces to form a whole building. Simplicity of reading derives from the context of detailed and complex information, properly arranged. A most unconventional design strategy is revealed: *to clarify, add detail.*

Michel Etienne Turgot and Louis Bretez, *Plan de Paris* (Paris, 1739), plate II. Above, *The Isometric Map of Midtown Manhattan,* © 1989 The Manhattan Map Company. All rights reserved.

[1] Italo Calvino's *Invisible Cities* (San Diego, 1974) records this texture of storied detail: cities are "relationships between the measurements of its space and the events of its past: the height of a lamp-post and the distance from the ground of a hanged usurper's swaying feet; the line strung from the lamp-post to the railing opposite and the festoons that decorate the course of the queen's nuptial procession; the height of that railing and the leap of the adulterer who climbed over it at dawn; the tilt of a guttering cat's progress along it as he slips into the same window; the firing range of a gunboat which has suddenly appeared beyond the cape and the bomb that destroys the guttering; the rips in the fish-net and the three old men seated on the dock mending nets and telling each other for the hundredth time the story of the gunboat of the usurper, who some say was the queen's illegitimate son, abandoned in his swaddling clothes there on the dock." On Calvino and maps, see a fine essay by Marc Treib, "Mapping Experience," *Design Quarterly*, 115 (1980).

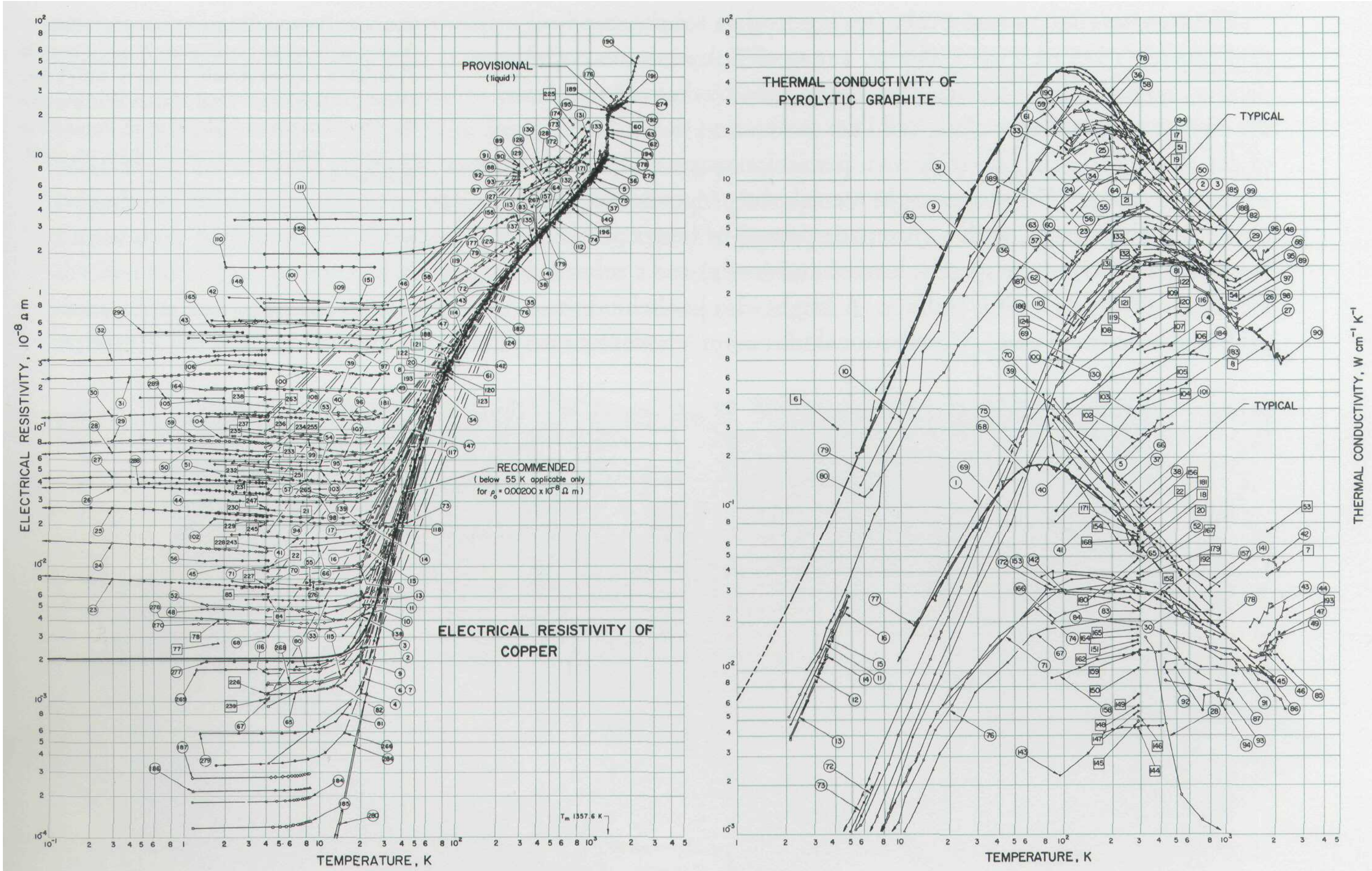
A high-resolution aerial photograph of Senlis, one of the oldest cities in France (construction started on this Notre Dame cathedral in 1153), arrays micro-details mixing into overall pattern. Encircling Senlis was once a broad strip of Gallo-Roman fortification, now replaced by houses, arranged by the memory of the old town's plan. Such intensity of detail is routinely reported in photographs, so much data that digitizing these images for computers requires 10^6 to 10^8 bits.

Robert Cameron, *Above Paris* (San Francisco, 1984), pp. 146-147.

Micro/macro composition also oversees this celebrated 1930 poster composed by the Soviet graphic artist Gustav Klutsis. The design and political point correspond—as the poster shows and also writes out, from collaborative work of many hands, one great plan will be fulfilled.

At work here is a critical and effective principle of information design. Panorama, vista, and prospect deliver to viewers the freedom of choice that derives from an overview, a capacity to compare and sort through detail. And that micro-information, like smaller texture in landscape perception, provides a credible refuge where the pace of visualization is condensed, slowed, and personalized.[2] These visual experiences are universal, rooted in human information-processing capacities and in the abundance and intricacy of everyday perceptions. Thus the power of micro/macro designs holds for every type of data display as well as for topographic views and landscape panoramas. Such designs can report immense detail, organizing complexity through multiple and (often) hierarchical layers of contextual reading.

[2] Jay Appleton, *The Experience of Landscape* (Chichester, 1975); John A. Jakle, *The Visual Elements of Landscape* (Amherst, 1987).



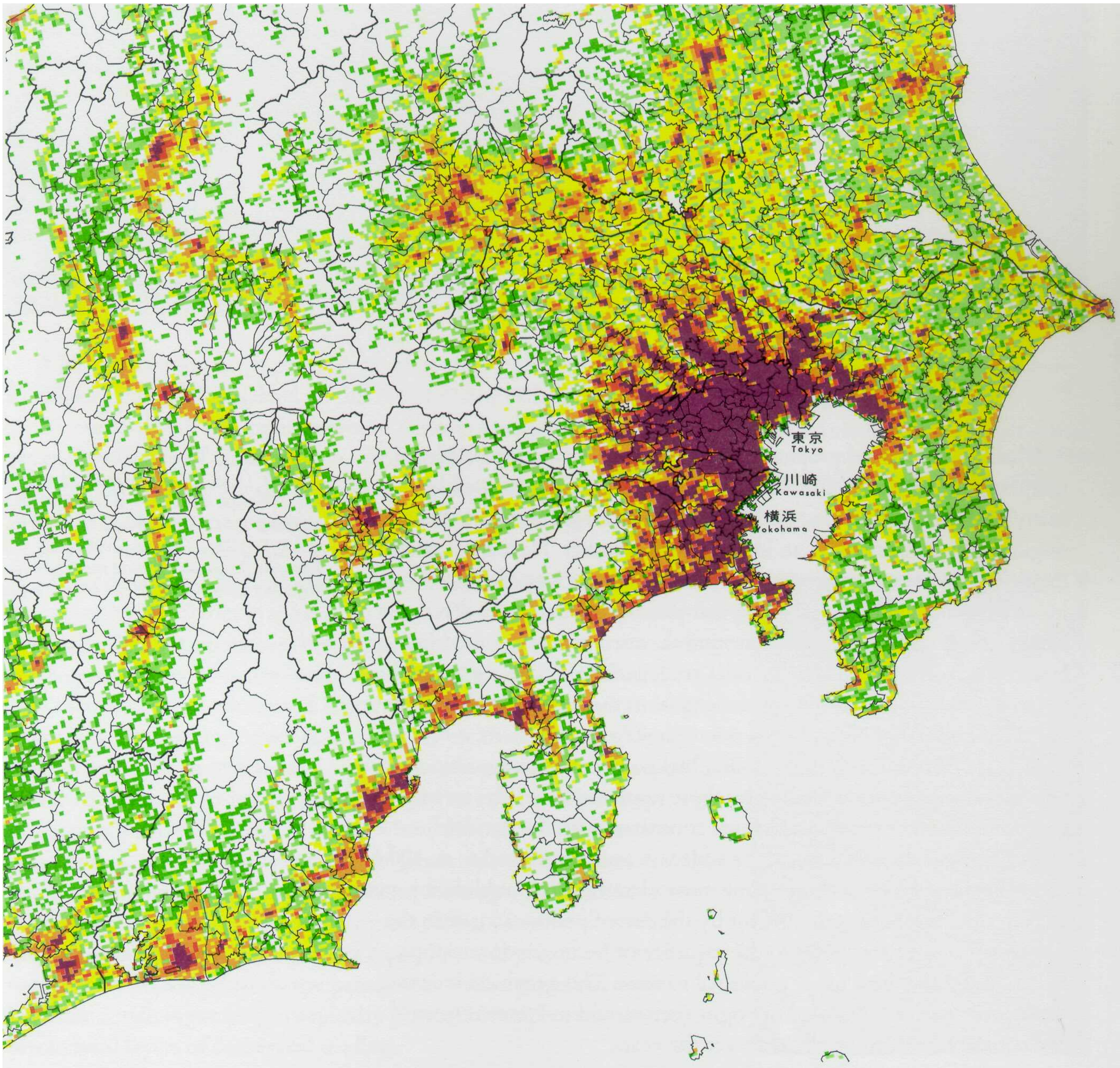
R. A. Matula, "Electrical Resistivity of Copper, Gold, Palladium, and Silver," *Journal of Physical and Chemical Reference Data,* 8 (1979), 1162; C. Y. Ho, R. W. Powell, and P. E. Liley, *Thermal Conductivity of the Elements. Journal of Physical and Chemical Reference Data,* 3 (1974), pp. 1-151, 1-244.

These multi-layered graphs report a clouded relationship between temperature and conductivity for various elements, as measured by many different laboratories. Each set of connected points comes from a single publication, cited by an identification number. Note how easily these displays organize the material, recording observations from several hundred studies and also enforcing comparisons among quite divergent results (this is science?) scattered around the correct curve, a solid line labeled **RECOMMENDED**. Since both scales are logarithmic, cycling through 3.5 to 6 orders of magnitude, deviations from the recommended curve are often quite substantial. In this micro/macro arrangement, 4 layers of data are placed in evidence—individual points measured within each study, connected curves formed by those results, and, finally, an overall conglomeration of curves (which are compared with the standard).

Still another slice of data can be added. A number, linked to an *alphabetical* list ordered by author's name, now identifies each published paper. A better method is to order the list by the *date* of publication; then the numerical codes correspond to the sequence of findings—for example, 61c indicates the third paper published in 1961. This graphical indexing depicts which study first had the right answer, and movement toward the correct curve can be tracked over the years.

These extraordinary statistical maps report data for thousands of tiny grid squares (1 km on a side). Below, a map of Tokyo shows population density; note smaller concentrations dotting the tracks radiating from the city, as people cluster along rail lines and station stops. At this level of detail, residents can find their own particular square and also see it in a broader context. The map at right records the proportion of children living at each location, with a systematic pattern of lower percentages in central Tokyo (where space is limited and costly) and a suburban ring teeming—relatively—with children. A bright idea lies behind these grid-square or mesh maps. Conventional blot maps (choropleth maps,

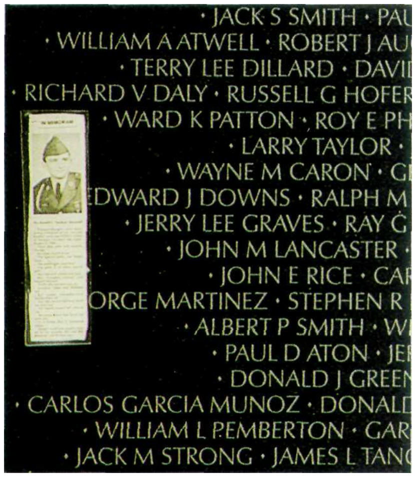
Statistics Bureau, Prime Minister's Office, *Statistical Maps on Grid Square Basis: The 1980 Population Census Results* (Tokyo, 1985). See Hidenori Kimura, "Grid Square Statistics for the Distribution and Mobility of Population in Japan," Statistics Bureau (Tokyo, no date), manuscript.



in the jargon) paint over areas formed by *given* geographic or political boundaries. The consequences are (1) sizes of areas are non-uniform, (2) colored-in areas are proportional to (often nearly empty) land areas instead of the activities depicted, with large unpopulated areas often receiving greatest visual emphasis, and (3) historical changes in political boundaries disrupt continuity of statistical comparisons.[3] Mesh maps finesse these problems. For these maps, the whole country of Japan was divided up in 379,000 equal-sized units and then, in a heroic endeavor, census data and addresses were collated to match the new grid squares. Arbitrary but statistically wise boundaries now cradle the micro-data.

[3] J. C. Müller, "Wahrheit und Lüge in Thematischen Karten — Zur Problematik der Darstellung Statistischer Sachverhalte," *Kartographische Nachrichten,* 35-2 (1985), 44-52. Other uses of mesh maps include describing flows; see Waldo R. Tobler, "A Model of Geographic Movement," *Geographical Analysis,* 13 (January 1981), 1-19.

THE Vietnam Veterans Memorial in Washington, D.C. achieves its visual and emotional strength by means of micro/macro design. From a distance the entire collection of names of 58,000 dead soldiers arrayed on the black granite yields a visual measure of what 58,000 means, as the letters of each name blur into a gray shape, cumulating to the final toll. When a viewer approaches, these shapes resolve into individual names. Some of the living seek the name of one particular soldier in a personal micro-reading; more than a few visitors here touch the etched, textured names. We focus on the tragic information; absent are the big porticoes, steps and stairs, and other marble paraphernalia usually attached to grand official monuments. Walking on a slight grade downward (approaching from either side), our first close reading is of panels no higher than a few names. But looking forward, the visitor sees names of the dead rising higher and higher, a statistical blur of marks in the distance with micro-detail at hand. The context is enlarged by calm reflections off polished black granite, reflections of the living and of trees, and, at a distance, of the Lincoln and Washington memorials toward which the walls angle.



An additional data dimension comes from the *ordering* of names. The memorial's designer, Maya Ying Lin, proposed that names be listed by date of death rather than alphabetically:

> . . . chronological listing was essential to her design. War veterans would find their story told, and their friends remembered, in the panel that corresponded with their tour of duty in Vietnam. Locating specific names with the aid of a directory would be like finding bodies on a battlefield. . . . Some initially disagreed. If 58,000 names were scattered along the wall, anyone looking for a specific name would wander around for hours and then leave in frustration. One solution seemed obvious: list everyone in alphabetical order. . . . But when a two-inch-thick Defense Department listing of Vietnam casualties was examined, thinking changed. There were over 600 Smiths; 16 people named James Jones had died in Vietnam. Alphabetical listing would make the Memorial look like a telephone book engraved in granite, destroying the sense of unique loss that each name carried. . . .[4]

[4] Jan C. Scruggs and Joel L. Swerdlow, *To Heal a Nation: The Vietnam Veterans Memorial* (New York, 1985), pp. 78-79.

Vietnam Veterans Memorial, *Directory of Names* (Washington, D.C., 1985). Shown here is an excerpt from the finder, a large book recording the name, rank, service, birthdate, deathdate, home town, and panel and line number locating each name on the stone memorial.

SMITH ROBERT GEORGE	PFC	AR	11 JUN 45	02 JAN 66	CLEVELAND	OH	4E	52
SMITH ROBERT HAROLD	SP4	AR	27 OCT 46	24 JAN 67	WARMINSTER	PA	14E	73
SMITH ROBERT JAMES	SSGT	AR	16 DEC 45	18 APR 68	ALBANY	NY	50E	41
SMITH ROBERT JEREMIAH	CPL	AR	16 MAY 47	29 SEP 67	BUFFALO	NY	27E	32
SMITH ROBERT JOE	SP4	AR	04 JUL 44	21 MAR 67	JACKSONVILLE	FL	17E	14
SMITH ROBERT JOHN	A1C	AF	15 OCT 42	25 JUN 65	SCARBORO	ME	2E	19
SMITH ROBERT JOSEPH	PFC	MC	04 AUG 48	26 AUG 68	COLUMBUS	GA	46W	34
SMITH ROBERT JR	PFC	AR	20 MAR 45	26 MAY 66	PHILADELPHIA	PA	7E	111
SMITH ROBERT L	SGT	AR	30 JUN 37	25 AUG 66	MILLINGTON	TN	10E	44
SMITH ROBERT LEE	SP4	AR	06 NOV 43	29 JAN 66	WELCH	WV	4E	115
SMITH ROBERT LEE	SSGT	AR	22 AUG 32	25 MAY 68	CHILLICOTHE	OH	67W	6
SMITH ROBERT LEE	LCPL	MC	09 JAN 46	31 MAY 68	MONROE	MI	62W	17
SMITH ROBERT LEE	PFC	MC	28 MAR 46	02 SEP 68	CINCINNATI	OH	45W	28
SMITH ROBERT LEE	PFC	AR	06 OCT 43	30 DEC 69	CHICAGO	IL	15W	111
SMITH ROBERT LEE JR	LCPL	MC	31 JUL 45	04 MAR 66	NEWPORT NEWS	VA	5E	110
SMITH ROBERT LEWIS	PFC	AR	05 APR 48	06 JUN 68	SMITHLAND	KY	59W	15
SMITH ROBERT LINDO	PFC	AR	22 JAN 40	17 FEB 66	SANFORD	NC	5E	43
SMITH ROBERT LOUIS	CPL	AR	27 MAY 47	08 MAR 67	ANGIER	NC	16E	42
SMITH ROBERT MICHAEL	SGT	AR	11 NOV 48	10 MAR 70	PEORIA	IL	13W	108

SMITH ROBERT NORMAN	COL	MC	20 SEP 26	19 AUG 69	TRUCKSVILLE	PA	19W	74
SMITH ROBERT SR	SGT	AR	28 MAY 32	21 OCT 66	ALEXANDRIA	LA	11E	96
SMITH ROBERT T	SGT	AR	01 AUG 44	12 APR 69	INDIANAPOLIS	IN	27W	67
SMITH ROBERT WALTER	SGT	AR	27 APR 47	20 JAN 69	LAKE CORMORANT	MS	34W	45
SMITH ROBERT WILBUR	CAPT	AF	02 JUL 44	17 APR 70	WASHINGTON	DC	11W	19
SMITH ROBERT WILLIAM	PFC	AR	02 AUG 47	12 NOV 66	WENTZVILLE	MO	12E	64
SMITH RODNEY HOWE	LTC	AR	02 AUG 31	03 JUN 67	ARLINGTON	VA	21E	53
SMITH ROGER LEE	SP4	AR	14 MAR 47	03 OCT 68	SOUTH POINT	OH	41W	2
SMITH RONALD C	SP4	AR	21 APR 46	03 MAR 67	DEARBORN	MI	16E	14
SMITH RONALD CARLTON	SP4	AR	18 SEP 44	14 APR 68	HATBORO	PA	50E	1
SMITH RONALD EUGENE	SFC	AR	29 MAR 40	28 NOV 70	COVINGTON	IN	6W	89
SMITH RONALD ORDON	SP4	AR	03 JUN 47	21 NOV 67	COVINGTON	TN	30E	60
SMITH RONALD LARRY	1LT	MC	02 MAR 36	23 FEB 69	HOGANSVILLE	GA	31W	24
SMITH RONALD LEE	PFC	AR	20 DEC 47	26 MAY 68	BEECH GROVE	IN	65W	1
SMITH RONNIE WAYNE	PFC	MC	28 SEP 48	28 MAY 68	HUNTSVILLE	AL	64W	16
SMITH RONNY	PFC	MC	04 FEB 49	10 MAY 69	LENA	MS	25W	43
SMITH ROY	CPL	MC	11 MAY 46	20 MAY 67	BIRMINGHAM	AL	20E	65
SMITH ROY MILTON	SP4	AR	31 MAR 50	19 FEB 71	HOUSTON	TX	5W	122

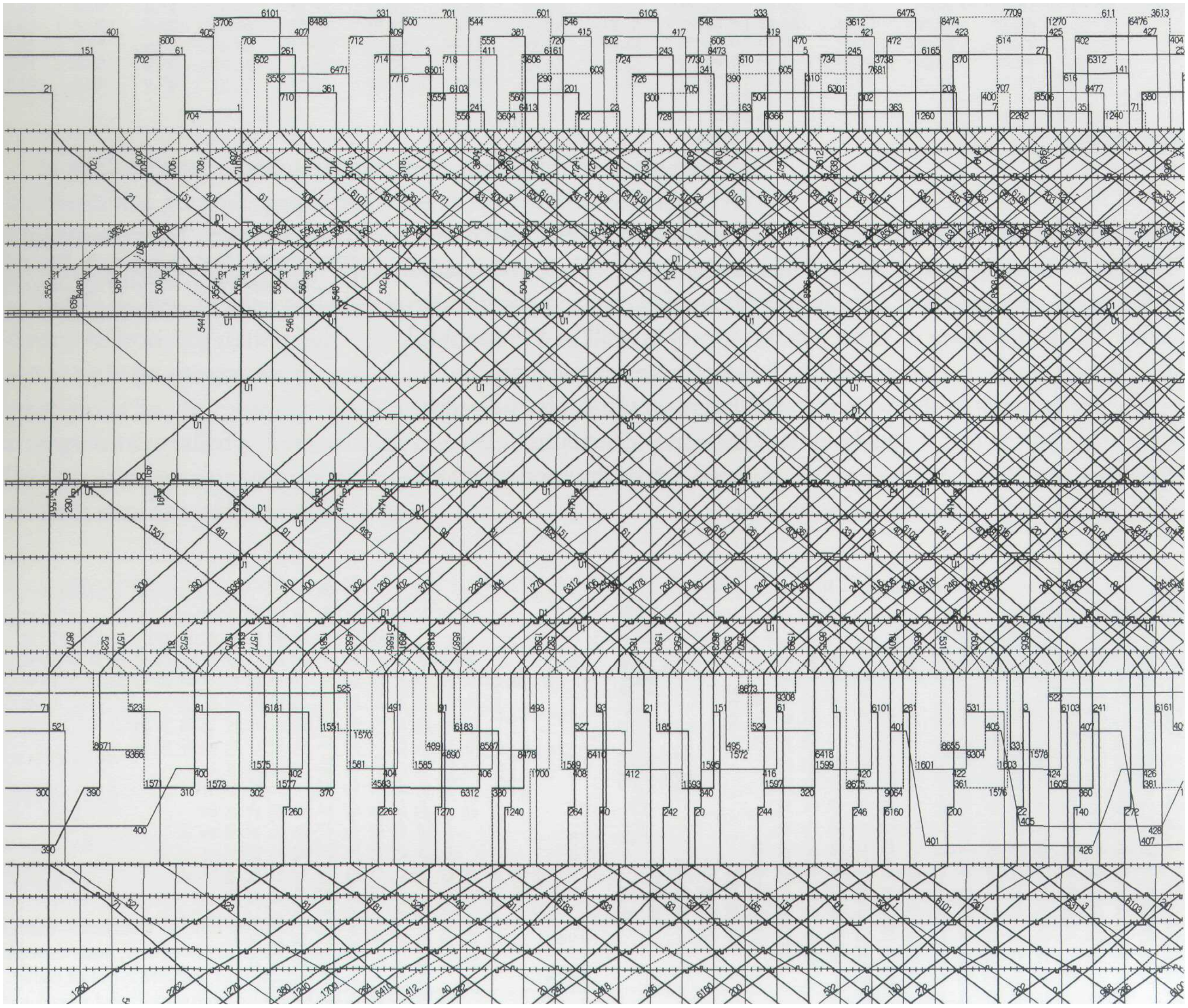
Thus the names on stone triple-function: to memorialize each person who died, to make a mark adding up the total, and to indicate sequence and approximate date of death. A directory-book alphabetically lists all the names and serves as a finder, pointing viewers to the location of a single engraved name.

The spirit of the *individual* created by the wall—both of each death and of each viewer personally editing — decisively affects how we see other visitors. The busloads of tourists appear not so much as crowds but rather as many separate individual faces, not as interruptions at an architectural performance but rather as our colleagues.[5]

[5] Since installation in 1982, the Vietnam Veterans Memorial has become the most visited monument in Washington. Some four million people saw it in 1988. "Maya Lin's Unwavering Vision," *The Washington Post*, February 13, 1989, B1, B6.

GRAPHICAL timetables also exemplify the multiplicity and wholeness of micro/macro design. Described here is the overall structure of a railroad system, as the individual lines aggregate into systematic patterns. This computer-graphical timetable shown here governs Japanese high-speed trains, or *Shinkansen.* Station stops are plotted down the side of the grid; time of day runs across the top; diagonal lines show the space-time path of each train. The Tokyo control-room directing these high-speed trains is filled with these graphical timetables, long paper strips used to help oversee thousands of journeys each day — a task which makes clear the enormous advantages *of seeing* information rather than tabulating data. Similar charts are also used for planning new schedules, with different interest groups negotiating where a train should stop and the frequency of service as they design a graphical timetable.[6]

[6] Hiroaki Shigehara, *Ressha Daiya* [Train Diagram] (Tokyo, 1983). An enchanting story of graphical-timetable design is told by Hideo Ohki, "Transportation of Professional Baseball Spectators by Seibu Railways, "*Japanese Railway Engineering,* 19 (1979), 19-23, describing a small railway serving baseball spectators. Considerations include irregular length of games, and spectators leaving early in event of a runaway. Railway workers monitor the game on television in order to adjust dynamically the train graph (as it is called, in a logic so visual that the graph entirely replaces entabled times).



Operation diagram for 12:00 noon, July 25, 1985, Tokaido and Sanyo Shinkansen Lines (bullet train), Japanese National Railroad control room, Tokyo.

Stem-and-leaf plots of statistical analysis also rely on micro/macro design. Each data point simultaneously states its value and fills a space representing one counted unit, like the names on the Vietnam Veterans Memorial, with those spaces in turn assembling to form a profile of the overall univariate distribution. Envisioned here are the heights of 218 volcanoes; each individual number helps to build the histogram. Micro-

0|9 = 900 feet

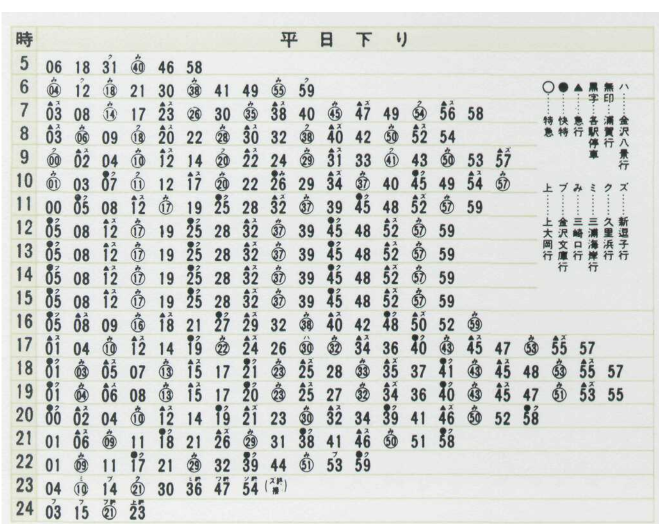
0	98766562
1	97719630
2	69987766544422211009850
3	876655412099551426
4	9998844331929433361107
5	97666666554422210097731
6	898665441077761065
7	98855431100652108073
8	653322122937
9	377655421000493
10	0984433165212
11	4963201631
12	45421164
13	47830
14	00
15	676
16	52
17	92
18	5
19	39730

Stem-and-leaf displays:
heights of 218 volcanoes, unit 100 feet.

19|3 = 19,300 feet

data has replaced the information-empty bars of a traditional barchart. This idea of making each graphical element *repeatedly* effective animated design of the stem-and-leaf plot. In describing his invention, John Tukey wrote: "If we are going to make a mark, it may as well be a meaningful one. The simplest—and most useful—meaningful mark is a digit."[7]

In a similar fashion, this train schedule below positions the individual departure times so that they add up to a frequency distribution. For trains that run often, leading hour-digits need not be repeated over and over, and, instead, minutes can be stacked:



時	平日下り
5	06 18 31 40 46 58
6	04 12 18 21 30 38 41 49 55 59
7	03 08 14 17 23 26 30 35 38 40 45 47 49 54 56 58
8	03 06 09 18 20 22 28 30 32 38 40 42 50 52 54
9	00 02 04 10 12 14 20 22 24 29 31 33 41 43 50 53 57
10	01 03 07 11 12 17 20 22 26 29 34 37 40 45 49 54 57
11	00 05 08 12 17 19 25 28 32 37 39 45 48 52 57 59
12	05 08 12 17 19 25 28 32 37 39 45 48 52 57 59
13	05 08 12 17 19 25 28 32 37 39 45 48 52 57 59
14	05 08 12 17 19 25 28 32 37 39 45 48 52 57 59
15	05 08 12 17 19 25 28 32 37 39 45 48 52 57 59
16	05 08 09 16 18 21 27 29 32 38 40 42 48 50 52 59
17	01 04 10 12 14 19 22 24 26 30 32 34 36 40 43 45 47 53 55 57
18	01 03 05 07 13 15 17 21 23 25 28 33 35 37 41 43 45 48 53 55 57
19	01 04 06 08 13 15 17 20 23 25 27 32 34 36 40 43 45 47 51 53 55
20	00 02 04 10 12 14 19 21 23 30 32 34 39 41 46 50 52 58
21	01 06 09 11 18 21 26 29 31 38 41 46 50 51 58
22	01 09 11 17 21 29 32 39 44 51 53 59
23	04 10 14 21 30 36 47 54
24	03 15 21 23

Keihin Express Line at Yokohama Station, Sagami Tetsudo Company, 1985 timetable, p. 76. Encodings indicate types of trains (super express, commuter, and so on) and various local stops.

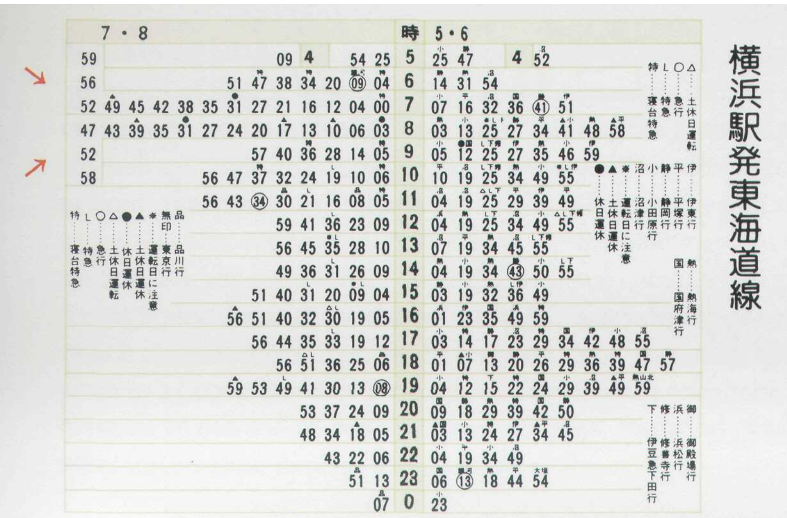
[7] John W. Tukey, "Some Graphic and Semigraphic Displays," in T. A. Bancroft, ed., *Statistical Papers in Honor of George W. Snedecor* (Ames, Iowa, 1972), p. 296.

Reported is the overall time distribution of 292 daily trains, with peaks during morning and evening rush hours. The shrewd design saves 777 characters, avoiding this typographical extravaganza below, which lacks the intensive annotation of the stem-and-leaf original and also fails to provide clear testimony about frequency of train service by hour.[8]

[8] The stem-and-leaf schedule contains 619 numbers; the typographic version 1,396 numbers and periods. Thus the stem-and-leaf schedule saves 777 characters, and, more importantly, gives a much better sense of comparison of train times.

5.06	7.17	8.28	9.31	10.40	11.57	13.12	14.28	15.45	16.52	17.53	18.45	19.40	20.39	21.51	23.36
5.18	7.23	8.30	9.33	10.45	11.59	13.17	14.32	15.48	16.59	17.55	18.48	19.43	20.41	21.58	23.47
5.31	7.26	8.32	9.41	10.49	12.05	13.19	14.37	15.52	17.01	17.57	18.53	19.45	20.46	22.01	23.54
5.40	7.30	8.38	9.43	10.54	12.08	13.25	14.39	15.57	17.04	18.01	18.55	19.47	20.50	22.09	24.03
5.46	7.35	8.40	9.50	10.57	12.12	13.28	14.45	15.59	17.10	18.03	18.57	19.51	20.52	22.11	24.15
5.58	7.38	8.42	9.53	11.00	12.17	13.32	14.48	16.05	17.12	18.05	19.01	19.53	20.58	22.17	24.21
6.04	7.40	8.50	9.57	11.05	12.19	13.37	14.52	16.08	17.14	18.07	19.04	19.55	21.01	22.21	24.23
6.12	7.45	8.52	10.01	11.08	12.25	13.39	14.57	16.09	17.19	18.13	19.06	20.00	21.06	22.29	
6.18	7.47	8.54	10.03	11.12	12.28	13.45	14.59	16.16	17.22	18.15	19.08	20.02	21.09	22.32	
6.21	7.49	9.00	10.07	11.17	12.32	13.48	15.05	16.18	17.24	18.17	19.13	20.04	21.11	22.39	
6.30	7.54	9.02	10.11	11.19	12.37	13.52	15.08	16.21	17.26	18.21	19.15	20.10	21.18	22.44	
6.38	7.56	9.04	10.12	11.25	12.39	13.57	15.12	16.27	17.30	18.23	19.17	20.12	21.21	22.51	
6.41	7.58	9.10	10.17	11.28	12.45	13.59	15.17	16.29	17.32	18.25	19.20	20.14	21.26	22.53	
6.49	8.03	9.12	10.20	11.32	12.48	14.05	15.19	16.32	17.34	18.28	19.23	20.19	21.29	22.59	
6.55	8.06	9.14	10.22	11.37	12.52	14.08	15.25	16.38	17.36	18.33	19.25	20.21	21.31	23.04	
6.59	8.09	9.20	10.26	11.39	12.57	14.12	15.28	16.40	17.40	18.35	19.27	20.23	21.38	23.10	
7.03	8.18	9.22	10.29	11.45	12.59	14.17	15.32	16.42	17.43	18.37	19.32	20.30	21.41	23.14	
7.08	8.20	9.24	10.34	11.48	13.05	14.19	15.37	16.48	17.45	18.41	19.34	20.32	21.46	23.21	
7.14	8.22	9.29	10.37	11.52	13.08	14.25	15.39	16.50	17.47	18.43	19.36	20.34	21.50	23.30	

In all these micro/macro designs, the same ink serves more than one informational purpose; graphical elements are multifunctioning. This suggests a missed opportunity in the stem-and-leaf timetable—surely leaves of numbers can grow from *both* sides of a central stem. And so it is; the finely detailed timetable below records trains running in several directions from the station, with the platforms 7-8 at left and platforms 5-6 at right (at the arrows, note how numbers serpentine around a bend when times for the morning rush hour exceed the grid). Sometimes this arrangement is called a "back to back stem and leaf plot." Nonetheless, Japanese train passengers have managed to use the schedules for decades without ever knowing the fancy name.



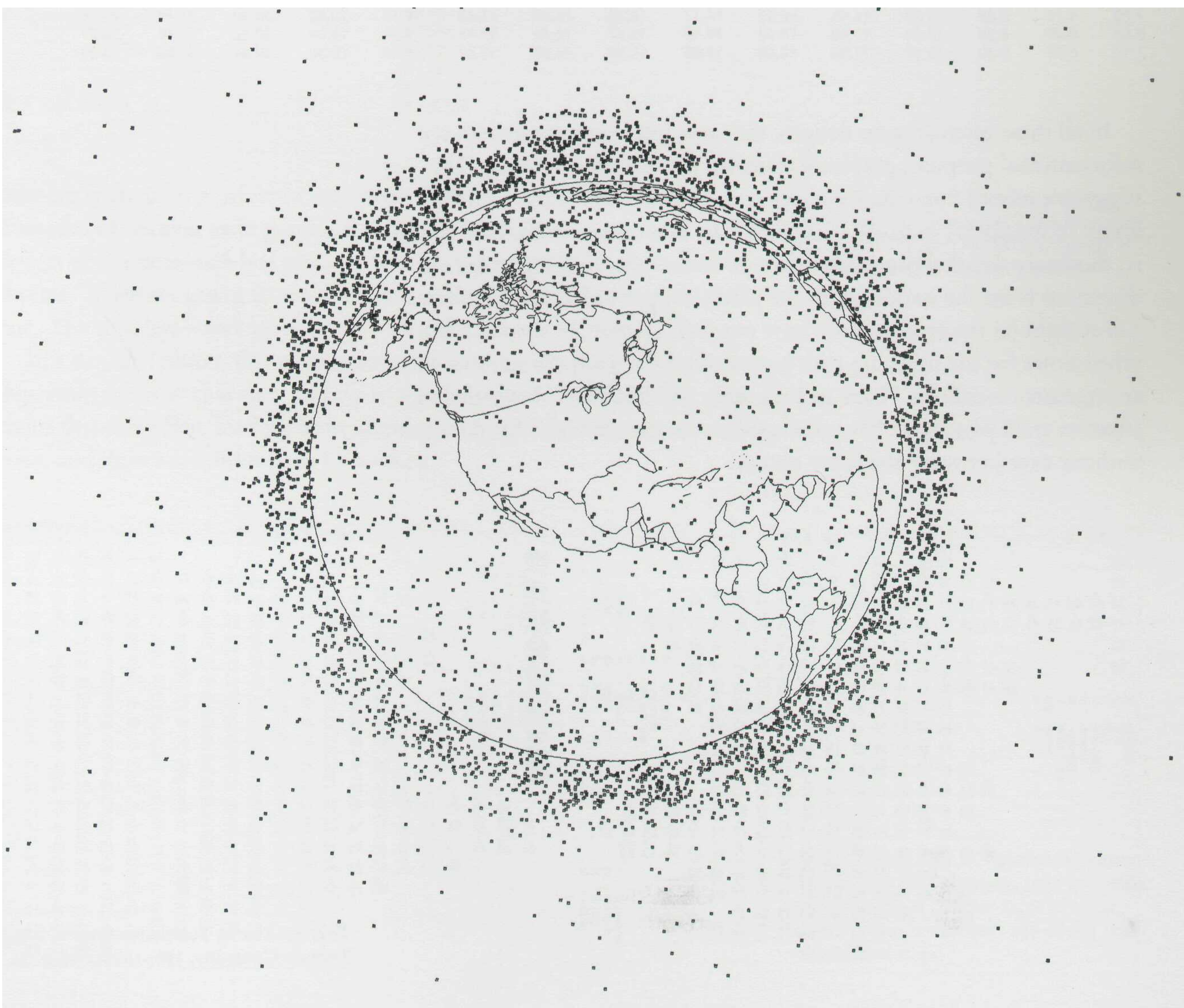
横浜駅発東海道線

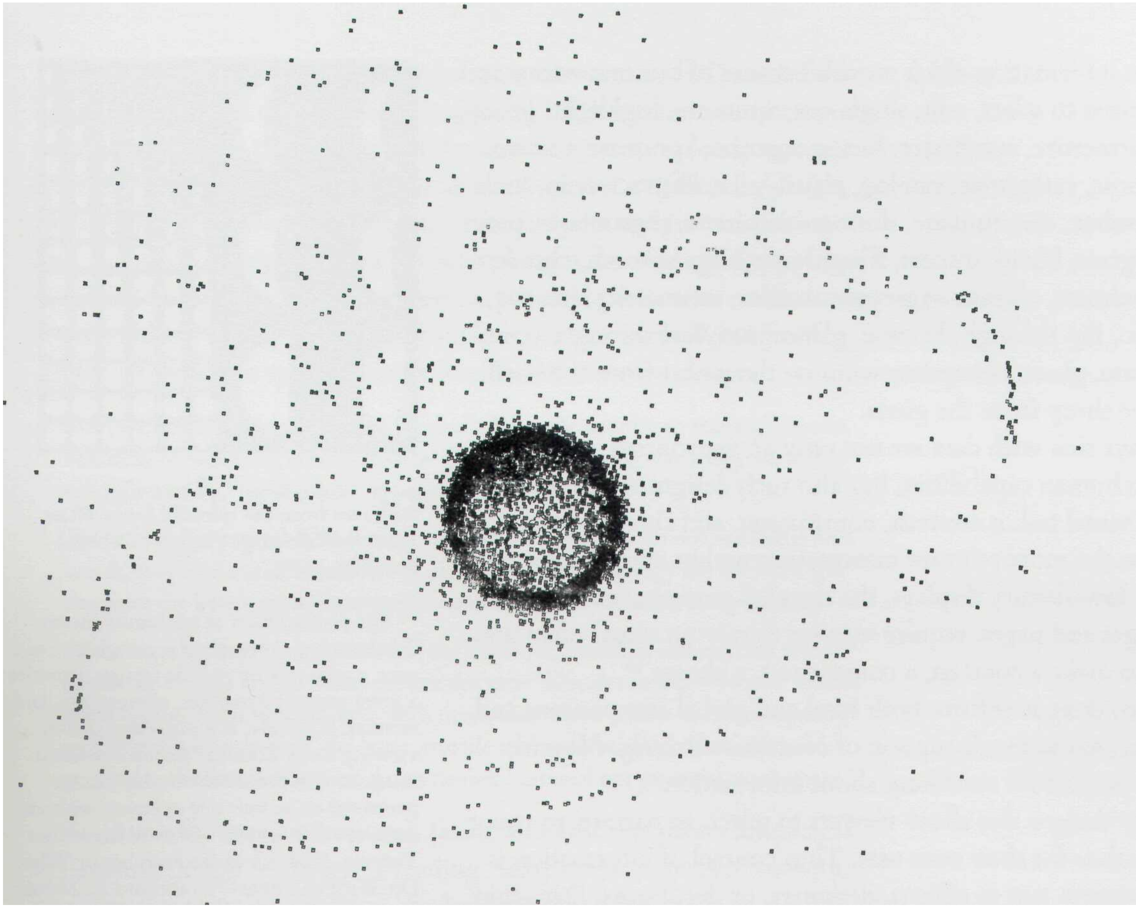
7・8	時	5・6
59 09 4 54 25	5	25 47 4 52
56 51 47 38 34 20 (09) 04	6	14 31 54
52 49 45 42 38 35 31 27 21 16 12 04 00	7	07 16 32 36 (41) 51
47 43 39 35 31 27 24 20 17 13 10 06 03	8	03 13 25 27 34 41 48 58
52 57 40 36 28 14 05	9	05 12 25 27 35 46 59
58 56 47 37 32 24 19 10 06	10	10 19 25 34 49 55
56 43 (34) 30 21 16 08 05	11	04 19 25 29 39 49
59 41 36 23 09	12	04 19 25 34 49 55
56 45 35 28 10	13	07 19 34 45 55
49 36 31 26 09	14	04 19 34 (43) 50 55
51 40 31 20 09 04	15	03 19 32 36 49
56 51 40 32 30 19 05	16	01 23 35 49 59
56 44 35 33 19 12	17	03 14 17 23 29 34 42 48 55
56 51 36 25 06	18	01 07 13 20 26 29 36 39 47 57
59 53 49 41 30 13 (08)	19	04 12 15 22 24 29 39 49 59
53 37 24 09	20	09 18 29 39 42 50
48 34 18 05	21	03 13 24 27 34 45
43 22 06	22	04 19 34 49
51 13	23	06 (13) 18 44 54
07	0	23

Tokaido Line at Yokohama Station, Sagami Tetsudo Company, 1985 timetable, p. 72.

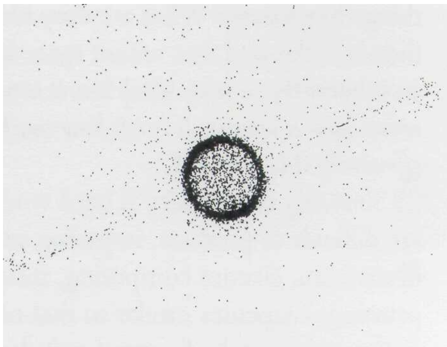
EACH at least as big as this drawing of the earth, some 7,000 pieces of space debris—operating and dead satellites, explosion fragments from rocket engines, garbage bags and frozen sewage dumped by astronauts, shrapnel from antisatellite weapons tests, 34 nuclear reactors and their fuel cores, an escaped wrench and a toothbrush—now orbit our world. Only about 5 percent are working satellites. By means of extraordinary data recording and analysis, military computers identify and then track *each* of these 7,000 objects (>10 cm in diameter), in order to diffferentiate the debris from a missile attack, for which we may be thankful. Space is not totally self-cleaning; some of the stuff will be up there for centuries, endangering people and satellites working in space as well as inducing spurious astronomical observations. The risk of a damaging collision is perhaps 1 in 500 during several years in orbit. The volume of debris has doubled about every 5 years; future testing of space weapons will accelerate the trashing of space.[9]

[9] Donald J. Kessler and Burton G. Cour-Palais, "Collision Frequency of Artificial Satellites: The Creation of a Debris Belt," *Journal of Geophysical Research*, 83 (June 1, 1978), 2637-2646; Donald J. Kessler, "Earth Orbital Pollution," in Eugene C. Hargrove, ed., *Beyond Spaceship Earth* (San Francisco, 1986), 47-65; Nicholas L. Johnson, "History and Consequences of On-orbit Break-ups," in *Space Debris, Asteroids and Satellite Orbits*, D. J. Kessler, E. Grim, and L. Sehnal, eds., *Advances in Space Research*, 5 (Oxford, 1985), 11-19; Eliot Marshall, "Space Junk Grows with Weapons Tests," *Science*, 230 (October 25, 1985), 424-425; Joel R. Primack, "Gamma-Ray Observations of Orbiting Nuclear Reactors," *Science*, 244 (April 28, 1989), 407-408.





The consequences (as of 0:00 hours Universal time, July 1, 1987) are shown in these phenomenal and disheartening micro/macro images, as a multiplicity of 7,000 dots adds to the overall pattern of orbital pollution. Most of the debris is relatively close to earth; a more distant view shows a ring formed by geosynchronous satellites. Not shown are some 50,000 smaller objects (size between 1 cm and 10 cm), as well as 10 billion to 100 billion paint chips now in orbit.



NEARLY all micro/macro designs of this chapter have portrayed large quantities of data at high densities, up to thousands of bits per square centimeter and 20 million bits per page, pushing the limits of printing technology. Such quantities are thoroughly familiar, although hardly noticed: the human eye registers 150 million bits, the 35 mm slide some 25 million bits, conventional large-scale topographic maps up to 150 million bits, the color screen of a small personal computer 8 million bits. Typographic densities are also substantial; a few reference books report 28,000 characters per page, books on non-fiction best-seller lists from 5,000 to 15,000 characters per page, and the world's telephone books run between 10,000 and 18,000 characters per page. Statistical graphics and other information displays should do so well.

Illustrations provided by Nicholas L. Johnson, Teledyne Brown Engineering, Colorado Springs, Colorado. Dots are not to scale of Earth.

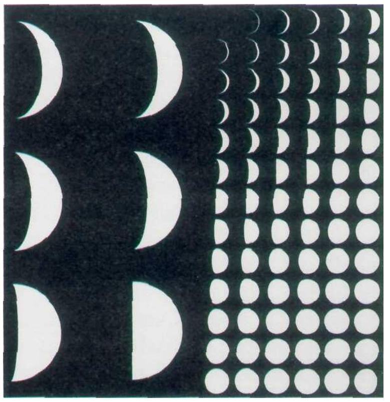
We thrive in information-thick worlds because of our marvelous and everyday capacities to select, edit, single out, structure, highlight, group, pair, merge, harmonize, synthesize, focus, organize, condense, reduce, boil down, choose, categorize, catalog, classify, list, abstract, scan, look into, idealize, isolate, discriminate, distinguish, screen, pigeonhole, pick over, sort, integrate, blend, inspect, filter, lump, skip, smooth, chunk, average, approximate, cluster, 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.

Visual displays rich with data are not only an appropriate and proper complement to human capabilities, but also such designs are frequently optimal. If the visual task is contrast, comparison, and choice—as so often it is—then the more relevant information within eyespan, the better. Vacant, low-density displays, the dreaded posterization of data spread over pages and pages, require viewers to rely on visual memory—a weak skill—to make a contrast, a comparison, a choice.[10]

Micro/macro designs enforce both local and global comparisons and, at the same time, avoid the disruption of context switching. All told, exactly what is needed for reasoning about information.[11]

High-density designs also allow viewers to select, to narrate, to recast and personalize data for their own uses. Thus control of information is given over to *viewers*, not to editors, designers, or decorators. Data-thin, forgetful displays move viewers toward ignorance and passivity, and at the same time diminish the credibility of the source. Thin data rightly prompts suspicions: "What are they leaving out? Is that really everything they know? What are they hiding? Is that all they did?" Now and then it is claimed that vacant space is "friendly" (anthropomorphizing an inherently murky idea) but *it is not how much empty space there is, but rather how it is used. It is not how much information there is, but rather how effectively it is arranged.*

Showing complexity is hard work. Detailed micro/macro designs are difficult to produce, imposing substantial costs for data collection, illustration, custom computing, image processing, production, and fine printing—expenses similar to that of first-class cartography (which, in the main, can be financed only by governments). The conventional economies of declining costs for each additional data bit will usually be offset by a proliferation of elaborate complexities provoked by the interacting graphical elements. Still, a single high-density page can replace twenty scattered posterizations, with a possible savings when total expenses are assessed (data collection and analysis, design, paper, production, printing, binding, warehousing, and shipping). And our readers might keep that one really informative piece of paper, although they will surely discard those twenty posterizations.



Redrawn from the splendid *Lunar Phase Poster* (Middleburg, Virginia: Celestial Products, 1987).

[10] The posterization at left hardly shows the changing moon phases; at right, however, a sequence of 78 little images provides a good sense of dynamics, comparison, and context. Similarly, it is suggested that in viewing x-ray films to "search a reduced image so that the whole display can be perceived on at least one occasion without large eye movement." Edward Llewellyn Thomas, "Advice to the Searcher or What Do We Tell Them?" in Richard A. Monty and John W. Senders, eds., *Eye Movements and Psychological Processes* (Hillsdale, New Jersey, 1976), p. 349.

[11] In user interfaces for computers, a problem undermining information exchange between human and software is "constant *context switches.* By this we mean that the user is not presented with one basic display format and one uniform style of interaction, but instead, with frequent changes: A scatterplot is present; it goes away, and is replaced by a menu; the menu goes away, and is replaced by the scatterplot; and so on. While the menu is present, the user cannot see the scatterplot, and vice versa. This means that users constantly have to adjust to a changing visual environment rather than focusing on the data. The user is also forced to remember things seen in one view so that he or she can use the other view effectively. This means that the user's short-term memory is occupied with the incidentals rather than with the significant issues of analysis." Andrew W. Donoho, David L. Donoho, and Miriam Gasko, "MacSpin: Dynamic Graphics on a Desktop Computer," *Computer Graphics & Applications* (July 1988), p. 58.

What about confusing clutter? Information overload? Doesn't data have to be "boiled down" and "simplified"? These common questions miss the point, for the quantity of detail is an issue completely separate from the difficulty of reading. *Clutter and confusion are failures of design, not attributes of information.* Often the less complex and less subtle the line, the more ambiguous and less interesting is the reading. Stripping the detail out of data is a style based on personal preference and fashion, considerations utterly indifferent to substantive content. What Josef Albers wrote about typography is true for information design:

> The concept that "the simpler the form of a letter the simpler its reading" was an obsession of beginning constructivism. It became something like a dogma, and is still followed by "modernistic" typographers.
>
> This notion has proved to be wrong, because in reading we do not read letters but words, words as a whole, as a "word picture." Ophthalmology has disclosed that the more the letters are differentiated from each other, the easier is the reading.
>
> Without going into comparisons and the details, it should be realized that words consisting of only capital letters present the most difficult reading—because of their equal height, equal volume, and, with most, their equal width. When comparing serif letters with sans-serif, the latter provide an uneasy reading. The fashionable preference for sans-serif in text shows neither historical nor practical competence.[12]

[12] Josef Albers, *Interaction of Color* (New Haven, 1963; revised edition, 1975), p. 4.

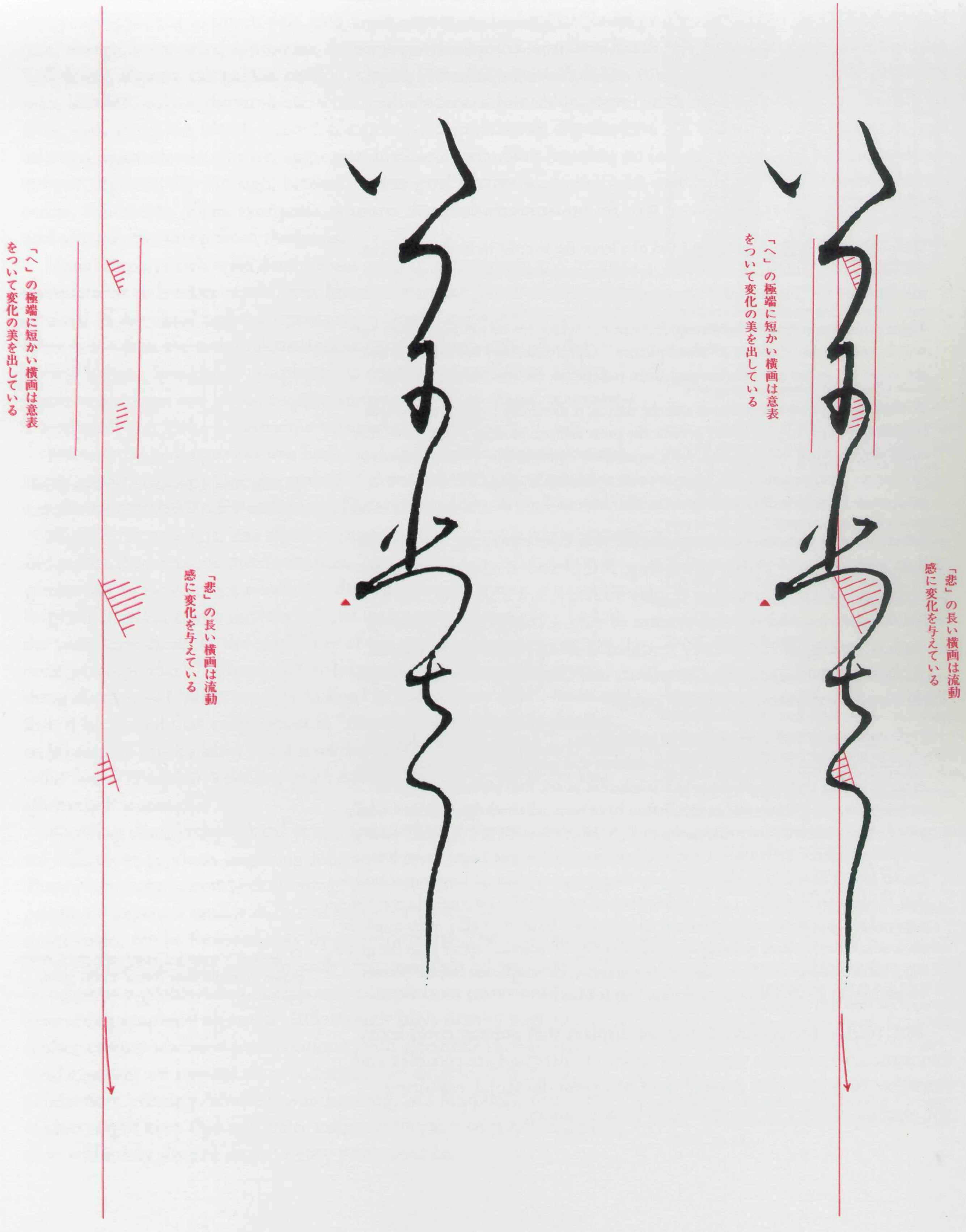
So much for the conventional, facile, and false equation: simpleness of data and design = clarity of reading. Simpleness is another aesthetic preference, not an information display strategy, not a guide to clarity. What we seek instead is a rich texture of data, a comparative context, an understanding of complexity revealed with an economy of means.

Robert Venturi opens his *Complexity and Contradiction in Architecture* with a broad extension of Albers' point:

> I like complexity and contradiction in architecture.... I speak of a complex and contradictory architecture based on the richness and ambiguity of modern experience, including that experience which is inherent in art. Everywhere, except in architecture, complexity and contradiction have been acknowledged, from Gödel's proof of inconsistency in mathematics to T. S. Eliot's analysis of "difficult" poetry and Joseph Albers' definition of the paradoxical quality of painting.... Architects can no longer afford to be intimidated by the puritanically moral language of orthodox Modern architecture .... an architecture of complexity and contradiction has a special obligation toward the whole: its truth must be in its totality or its implications of totality. It must embody the difficult unity of inclusion rather than the easy unity of exclusion. . . . Where simplicity cannot work, simpleness results. Blatant simplification means bland architecture. Less is a bore.[13]

[13] Robert Venturi, *Complexity and Contradiction in Architecture* (New York, 1966), pp. 16-17.

But, finally, the deepest reason for displays that portray complexity and intricacy is that the worlds we seek to understand are complex and intricate. "God is in the details," said Mies van der Rohe, capturing the essential quality of micro/macro performances.



「へ」の極端に短かい横画は意表をついて変化の美を出している
「悲」の長い横画は流動感に変化を与えている
「へ」の極端に短かい横画は意表をついて変化の美を出している
「悲」の長い横画は流動感に変化を与えている

3 Layering and Separation

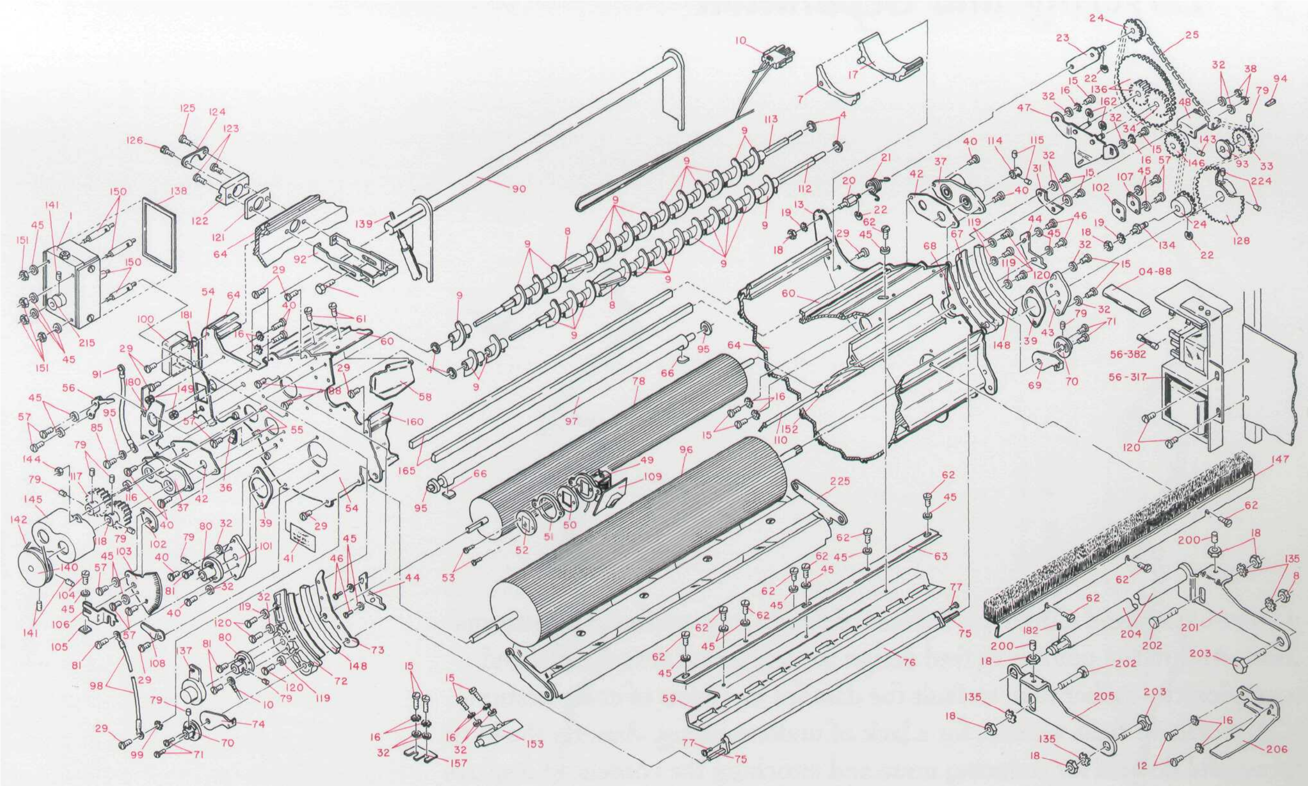
CONFUSION and clutter are failures of design, not attributes of information. And so the point is to find design strategies that reveal detail and complexity—rather than to fault the data for an excess of complication. Or, worse, to fault viewers for a lack of understanding. Among the most powerful devices for reducing noise and enriching the content of displays is the technique of layering and separation, visually stratifying various aspects of the data.

Effective layering of information is often difficult; for every excellent performance, a hundred clunky spectacles arise. An omnipresent, yet subtle, design issue is involved: the various elements collected together on flatland *interact*, creating non-information patterns and texture simply through their combined presence. Josef Albers described this visual effect as *1 + 1 = 3 or more*, when two elements show themselves along with assorted incidental by-products of their partnership — occasionally a basis for pleasing aesthetic effects but always a continuing danger to data exhibits.[1] Such patterns become dynamically obtrusive when our displays leave the relative constancy of paper and move to the changing video flatland of computer terminals. There, all sorts of unplanned and lushly cluttered interacting combinations turn up, with changing layers of information arrayed in miscellaneous windows surrounded by a frame of system commands and other computer administrative debris.

[1] Josef Albers, "One Plus One Equals Three or More: Factual Facts and Actual Facts," in Albers, *Search Versus Re-Search* (Hartford, 1969), pp. 17-18.

AT left a second color annotates the brush strokes of the calligrapher, Uboku Nishitani. By creating a distinct layer, the red commentary maintains detail, coherence, and serenity, in a crisp precision side-by-side with a gestural and expressive black line in this marriage of color and information. The saturated quality of the red partially offsets its lighter value and finer line (appropriate to meticulous annotation). Alone, each color makes a strong statement; together, a stronger one.

Uboku Nishitani, *Koyagire Daiishu [The First Seed of Koyagiri]*, volume 17 of *Shodo Giho Koza [Techniques in Calligraphy]* (Tokyo, 1972), p. 56. Redrawn.



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

Similarly, color effortlessly differentiates between annotation and annotated, in this skillful industrial-strength diagram separating 300 small parts and their identifying numbers.

What matters—inevitably, unrelentingly—is the proper *relationship* among information layers. These visual relationships must be in relevant proportion and in harmony to the substance of the ideas, evidence, and data conveyed. "Proportion and harmony" need not be vague counsel; their meanings are revealed in the practice of detailed visual editing of data displays. For example, in this train timetable a heavy-handed grid interacts with the type, generating a stripy texture and fighting with the scheduled times. The prominent top position in the table shows the least important information, a four-digit train identifier used by railroad personnel and nobody else:

New Jersey Transit, *Northeastern Corridor Timetable* (Newark, 1985).

Train No.	3701	XM 3301	3801	A 67	3 3803	3 3201	A3 51	3 3703	3 3807	3 3203	A3 61	3 3809	A3 47
	A.M.	A.M.	A.M.	A.M.	A.M.	A.M.	A.M.	A.M.	A.M.	A.M.	A.M.	A.M.	A.M.
New York, N.Y.	12.10	12.40	1.30	3.52	4.50	6.10	6.25	6.35	6.50	7.10	7.30	7.33	7.45
Newark, N.J. P	12.24	12.55	1.44	4.07	5.04	6.24	6.38	6.49	7.04	7.24	7.45	7.47	7.59
North Elizabeth	....	....	....	....	....	....	....	....	....	7.30	....	....	....
Elizabeth	12.31	1.03	1.51	....	5.11	6.31	....	6.56	7.11	7.32	....	7.54	....
Linden	12.36	....	1.56	....	5.16	6.36	....	7.01	7.15	7.37	....	7.59	....
North Rahway	....	....	....	....	....	....	....	7.03	....	7.39	....	....	....
Rahway	12.40	1.11	2.00	....	5.20	6.40	....	7.06	7.20	7.42	....	8.03	....
Metro Park (Iselin)	12.44	....	2.04	4.26	5.24	....	6.56	7.10	7.25	....	8.04	8.07	8.15
Metuchen	12.48	....	2.08	....	5.28	....	....	7.14	7.29	....	....	8.11	....
Edison	12.51	....	2.11	....	....	....	....	7.17	7.32	....	....	8.14	....
New Brunswick	12.55	....	2.15	....	5.35	....	7.05	7.21	7.35	....	....	8.18	8.25
Jersey Avenue	1.02	....	2.18	....	....	....	....	7.28	....	....	....	8.21	....
Princeton Jct. S	....	....	2.31	....	5.50	....	7.19	....	7.50	....	....	8.34	8.41
Trenton, N.J.	....	....	2.42	4.58	6.03	....	7.28	....	8.01	....	8.31	8.44	8.52

Train No.	3 3901	3 3811	3 3903	3 3813	3205	3815	3817	3819	3207	3821	3823	3825	3209	3827	3829	3831
	A.M.	A.M.	A.M.	A.M.	A.M.	A.M.	A.M.	A.M.	A.M.	A.M.	A.M.	A.M.	A.M.	P.M.	P.M.	P.M.
New York, N.Y.	7.50	8.05	8.25	8.40	8.50	9.10	9.40	10.10	10.25	10.40	11.10	11.40	11.50	**12.10**	**12.40**	**1.10**
Newark, N.J. P	8.04	8.19	8.39	8.54	9.04	9.24	9.54	10.24	10.39	10.54	11.24	11.54	**12.04**	**12.24**	**12.54**	**1.24**
North Elizabeth	8.10	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....
Elizabeth	8.13	8.26	8.46	9.01	9.11	9.31	10.01	10.31	10.46	11.01	11.31	**12.01**	**12.11**	**12.31**	**1.01**	**1.31**
Linden	8.18	8.31	8.51	9.06	....	9.36	10.06	10.36	....	11.06	11.36	**12.06**	....	**12.36**	**1.06**	**1.36**
North Rahway	8.20	8.33	8.54	....	....	....	....	....	....	....	....	....	....	....	....	....
Rahway	8.24	8.36	8.57	9.10	9.18	9.40	10.10	10.40	10.53	11.10	11.40	**12.10**	**12.18**	**12.40**	**1.10**	**1.40**
Metro Park (Iselin)	....	8.40	....	9.14	....	9.44	10.14	10.44	....	11.14	11.44	**12.14**	....	**12.44**	**1.14**	**1.44**
Metuchen	....	8.44	....	9.18	....	9.48	10.18	10.48	....	11.18	11.48	**12.18**	....	**12.48**	**1.18**	**1.48**
Edison	....	8.47	....	9.21	....	....	10.21	....	....	11.21	....	**12.21**	....	....	**1.21**	....
New Brunswick	....	8.50	....	9.25	....	9.54	10.25	10.54	....	11.25	11.54	**12.25**	....	**12.54**	**1.25**	**1.54**
Jersey Avenue	....	....	....	9.28	....	....	10.28	....	....	11.28	....	**12.28**	....	....	**1.28**	....
Princeton Jct. S	....	9.05	....	9.41	....	10.09	10.41	11.09	....	11.41	**12.09**	**12.41**	....	**1.09**	**1.41**	**2.09**
Trenton, N.J.	....	9.16	....	9.52	....	10.19	10.52	11.19	....	11.52	**12.19**	**12.52**	....	**1.22**	**1.52**	**2.20**

A redesign calms the dominating grid, moves the New York departure times to the very top, de-emphasizes less important data, and adds new information. A separating line is formed by tiny leader dots, which read as gray, making a distinction but not a barricade:

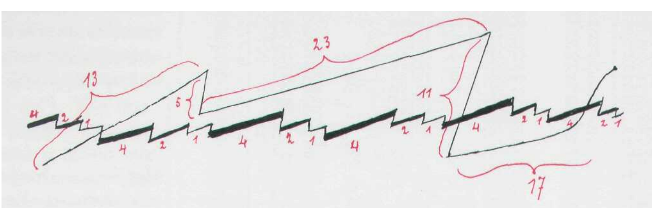
	am ●																								
New York, NY	12.10	12.40	1.30	3.52	4.50	6.10	6.25	6.35	6.50	7.10	7.30	7.33	7.45	7.50	8.05	8.25	8.40	8.50	9.10	9.40	10.10	10.25	10.40	11.10	11.40
Newark, NJP	12.24	12.55	1.44	4.07	5.04	6.24	6.38	6.49	7.04	7.24	7.45	7.47	7.59	8.04	8.19	8.39	8.54	9.04	9.24	9.54	10.24	10.39	10.54	11.24	11.54
North Elizabeth										7.30	. .	. .	. .	8.10	. .	. .	. .	. .	. .	. .	. .	. .	. .	. .	. .
Elizabeth	12.31	1.03	1.51	. .	5.11	6.31	. .	6.56	7.11	7.32	. .	7.54	. .	8.13	8.26	8.46	9.01	9.11	9.31	10.01	10.31	10.46	11.01	11.31	12.01
Linden	12.36	. .	1.56	. .	5.16	6.36	. .	7.01	7.15	7.37	. .	7.59	. .	8.18	8.31	8.51	9.06	. .	9.36	10.06	10.36	. .	11.06	11.36	12.06
North Rahway								7.03	. .	7.39	. .	. .	. .	8.20	8.33	8.54	. .	. .	. .	. .	. .	. .	. .	. .	. .
Rahway	12.40	1.11	2.00	. .	5.20	6.40	. .	7.06	7.20	7.42	. .	8.03	. .	8.24	8.36	8.57	9.10	9.18	9.40	10.10	10.40	10.53	11.10	11.40	12.10
Metro Park (Iselin)	12.44		2.04	4.26	5.24		6.56	7.10	7.25		8.04	8.07	8.15		8.40		9.14		9.44	10.14	10.44		11.14	11.44	12.14
Metuchen	12.48		2.08	. .	5.28		. .	7.14	7.29		. .	8.11	. .		8.44		9.18		9.48	10.18	10.48		11.18	11.48	12.18
Edison	12.51		2.11	. .	. .		. .	7.17	7.32		. .	8.14	. .		8.47		9.21		. .	10.21	. .		11.21	. .	12.21
New Brunswick	12.55		2.15	. .	5.35		7.05	7.21	7.35		. .	8.18	8.25		8.50		9.25		9.54	10.25	10.54		11.25	11.54	12.25
Jersey Avenue	1.02		2.18	. .	. .		. .	7.28	. .		. .	8.21	. .		. .		9.28		. .	10.28	. .		11.28	. .	12.28
Princeton JunctionS			2.31	. .	5.50		7.19		7.50		. .	8.34	8.41		9.05		9.41		10.09	10.41	11.09		11.41	12.09	12.41
Trenton, NJ			2.42	4.58	6.03		7.28		8.01		8.31	8.44	8.52		9.16		9.52		10.19	10.52	11.19		11.52	12.19	12.52
TRAIN NUMBER	3701	3301	3801	67	3803	3201	51	3703	3807	3203	61	3809	47	3901	3811	3903	3813	3205	3815	3817	3819	3207	3821	3823	3825
NOTES		XM	➤		3	3	➤ 3	3	3	3	➤ 3	3	➤ 3	3	3	3	3								

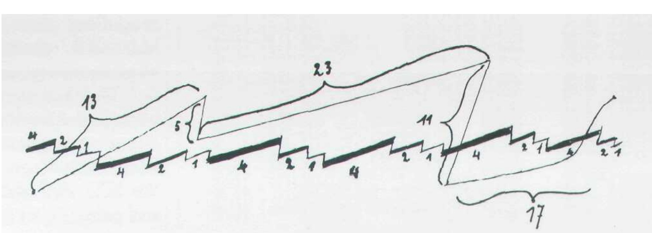
The focus is now given over to information, transparently organized by an *implicit* typographical grid, defined simply by the absence of type. Nevertheless, data-imprisonment spans centuries of information-design struggles. At right is a touchingly ramshackle grid from a 1535 edition of *Cosmographia*. But, from the virtuoso of typographic design: "Tables should not be set to look like nets with every number enclosed," wrote Jan Tschichold in *Asymmetric Typography:*

> The setting of tables, often approached with gloom, may with careful thought be turned into work of great pleasure. First, try to do without rules altogether. They should be used only when they are absolutely necessary. Vertical rules are needed only when the space between columns is so narrow that mistakes will occur in reading without rules. Tables without vertical rules look better; thin rules are better than thick ones.[2]

S.	S. M.	S.M.	S.M.	S.
0	0.0	12.16	20.38	30
1	0.26	12.37	20.40	29
2	0.52	12.58	21.0	28
3	1.18	13.19	21.11	7
4	1.44	13.40	21.21	26
5	2.10	14.0	21.31	25
6	2.36	14.20	21.40	24
7	3.2	14.40	21.49	23
8	3.28	14.59	21.58	22
9	3.53	15.18	22.6	21
10	2.19	15.37	22.14	20
11	4.45	15.55	22.21	19
12	5.10	16.13	22.28	18
13	5.35	16.31	22.35	17
14	6.0	16.48	22.41	16
15	6.25	17.5	22.47	15
16	6.50	17.22	22.52	4
17	7.15	17.38	22.57	1
18	7.39	17.54	23.2	12
19	8.3	18.10	23.7	11
20	8.27	18.5	23.11	10
21	8.51	18.40	23.15	9
22	9.15	18.55	23.18	8
23	9.39	19.9	23.21	7
24	10.2	19.23	23.23	6
25	10.2	19.36	23.25	5
26	10.48	19.49	23.27	4
27	11.10	20.2	23.28	3
28	11.32	20.14	23.29	2
29	11.54	20.26	23.30	1
30	12.16	20.38	23.30	0

Even quite small changes in line can have significant visual effects. For Paul Klee's sketch, the easy and graceful separation of black line and red commentary collapses into a mishmash when color and light/dark differences are minimized:





Paul Klee, *Symptomatic*. Pen and ink drawing, 1927/F2. From *Das bildnerische Denken* (Basel, 1956), p. 300.

2 Jan Tschichold, *Asymmetric Typography* (Basel, 1935; Toronto, 1967), p. 62.

Separate macro-annotation explains the micro-detail of hospital costs in this 26-day narrative of one person passing through an intensive care unit. The design is transparent to the disturbing information, as a layered polyphony of voices—time sequence, accounting data, commentary — weave together to trace out days, hours, minutes, dollars.

Redrawn from David Hellerstein, "The Slow, Costly Death of Mrs. K_____," *Harper's*, 268 (March 1984), 84-89.

Mrs. K___ has been taken to the emergency room of a renowned hospital on Manhattan's Upper East Side. The doctors "work her up." More than $200 worth of blood tests are ordered ("emer rm lab," "lab serology out"), $232 worth of X-rays taken, $97.50 worth of drugs administered. I never saw Mrs. K______, she wasn't in my hospital, I don't know her medical history. But I am a doctor, and can reconstruct from her hospital bill what is going on, more or less. She is sick, very sick.

Mrs. K___ has been moved to the Intensive Care Unit ("room ICU"). It costs $500 a day to stay in the ICU, base rate. California has the highest average ICU rates in the country: $632 a day. In Mississippi, the average is $265. ICUs were developed in the 1960s. They provide technological life-support systems and allow for extraordinary patient monitoring. An inhalation blood-gas monitor ("inhal blood gas mont") is being used to keep a close check on the amount of oxygen in her blood. Without the attention she is receiving in the ICU, Mrs. K______ might already be dead.

Mrs. K___ has been running a high fever. The doctors have sent cultures of her blood, urine, and sputum to the lab to find out why. She is put on gentamicin ("lab gentamycin troug"), a powerful antibiotic. Such strong drugs can have toxic side effects. Gentamicin kills bacteria, but can also cause kidney failure.

It is Mrs. K___"s fifth day at the hospital, and she is slipping closer to death: her lungs begin to fail. She is put on a respirator ("inhal respirator"), which costs $119 a day to rent and requires a special technician to operate. A hospital can buy the machine for about $15,000.

BILL TO	INSURANCE COVERAGE
JOHN K ____	BLUE CROSS STD 21

DATE	DESCRIPTION		TOTAL CHARGES
DETAIL	OF CURRENT CHARGES AND PAYMENTS		
09/23	EMER RM OTHER	5009000	119.00
09/23	EMER RM LAB	5006000	172.00
09/23	LAB SEROLOGY OUT	1406800	35.00
09/23	EMER RM EKG	5007000	61.00
09/23	X-RAY ABDOMEN	1501001	58.00
09/23	X-RAY CHEST RTN	1501009	58.00
09/23	X-RAY CHEST RTN	1501009	58.00
09/23	X-RAY CHEST RTN	1501009	58.00
09/23	PHARMACY	2601000	2.25
09/23	EMER RM PHARMACY	5002000	46.00
09/23	PHARMACY	2601000	49.25
09/23	ROOM ICU		500.00
09/24	LAB AUTO BLOOD CT	1402101	17.00
09/24	LAB ACT PAR THROM	1404001	27.00
09/24	LAB PROTH DETER	1404011	17.00
09/24	LAB BLOOD CULT	1405002	37.00
09/24	LAB BLOOD CULT	1405002	37.00
09/24	LAB CHEM-20	1401104	31.00
09/24	SP HEM CBC	1602010	28.00
09/24	SP HEM RETIC CT	1602046	17.00
09/24	SP HEM PLATELET CT	1602090	17.00
09/24	LAB SEROLOGY OUT	1406800	35.00
09/24	LAB MAGNES	1401042	27.00
09/24	LAB RTN URINAL	1403001	16.00
09/24	LAB RTN CULT	1405003	37.00
09/24	LAB BACTERIA SM	1405011	16.00
09/24	LAB RTN CULT	1405003	37.00
09/24	LAB DIFF	1402099	15.00
09/24	LAB PROT ELEC	1401049	53.00
09/24	LAB FUNGUS	1405008	31.00
09/24	LAB FUNGUS	1405008	31.00
09/24	LAB TBC CULT	1405014	42.00
09/24	LAB DIFF	1402099	15.00
09/24	LAB AUTO BLOOD CT	1402101	17.00
09/24	X-RAY CHEST-BED	1501128	74.00
09/24	PHARMACY	2601000	10.00
09/24	PHARMACY	2601000	8.00
09/24	PHARMACY	2601000	8.00
09/24	PHARMACY	2601000	4.50
09/24	SPECIMEN MUCUS TRAP	2709085	3.00
09/24	SPECIMEN MUCUS TRAP	2709035	3.00
09/24	INHAL BLOOD GAS MONT	2101034	354.00
09/24	ROOM ICU		500.00
09/25	LAB SALICYLATE	1401050	49.00
09/25	LAB AMMONIA	1401006	40.00
09/25	LAB CHEM-20	1401104	31.00
09/25	LAB PROTH DETER	1404011	17.00
09/25	LAB CHEM-8	1401111	31.00
09/25	LAB BACTERIA SM	1405011	16.00
09/25	LAB AUTO BLOOD CT	1402101	17.00
09/25	LAB AUTO BLOOD CT	1402101	17.00
09/25	LAB ACT PAR THROM	1404001	27.00
09/25	LAB TBC CULT	1405014	42.00
09/25	LAB TBC CULT	1405014	42.00
09/25	LAB FUNGUS	1405008	3L.00
09/25	LAB RTN CULT	1405003	37.00
09/25	LAB RTN CULT	1405003	37.00
09/25	CARDIO ROUTINE EKG	1801001	61.00
09/25	X-RAY CHEST-BED	1501128	74.00
09/25	X-RAY ABDOMEN	1501001	58.00
09/25	X-RAY CHEST-BED	1501128	74.00
09/25	X-RAY CHEST-BED	1501128	74.00
09/25	PHARMACY	2601000	13.50
09/25	PHARMACY	2601000	39.00
09/25	PHARMACY	2601000	3.70
09/25	PHARMACY	2601000	16.50
09/25	PHAR IV SOLUTIONS	2601003	16.00
09/25	PHARMACY	2601000	2.50
09/25	PHAR IV SOLUTIONS	2601003	13.50
09/25	PHAR IV SOLUTIONS	2601003	13.50
09/25	PHARMACY	2601000	3.35
09/25	PHARMACY	2601000	2.25
09/25	INHAL BLOOD GAS MONT	2101014	354.00
09/25	ROOM ICU		500.00
09/26	LAB PROTH DETER	1404011	17.00
09/26	LAB CHEM-8	1401111	31.00
09/26	LAB AUTO BLOOD CT	1402101	L7.00
09/26	LAB UR SODIUM	1401077	27.00
09/26	LAB UR POTASS	1401076	27.00
09/26	LAB DIFF	1402099	15.00
09/26	LAB CHEM-8	1401111	31.00
09/26	LAB GENTAMYCIN TROUG	1401112	27.00
09/26	CARDIO ROUTINE EKG	1801001	61.00
09/26	X-RAY CHEST BED	1501128	74.00
09/26	PHARMACY	2601000	31.20
09/26	PHARMACY	2601000	3.70
09/26	PHARMACY	2601000	13.50
09/26	PHARMACY	2601000	39.00
09/27	LAB CHEM-8	1401111	31.00
09/27	LAB PROTH DETER	1404011	17.00
09/27	LAB DIFF	1402099	15.00
09/27	LAB AUTO BLOOD CT	1402101	17.00
09/27	LAB ACT PAR THROM	1404001	27.00
09/27	LAB CHEM-8	1401111	31.00
09/27	LAB CHEM-20	1401104	31.00
09/27	LAB CHEMISTRY OUT	1401800	10.00
09/27	LAB FECES CULT	1405007	40.00
09/27	CARDIO ROUTINE EKG	1801001	61.00
09/27	BLD BK ANTIBDY SCRN	1701004	23.00
09/27	BLD BK ADMIN FEE	1701028	69.00
09/27	PHAR IV SOLUTIONS	2601003	37.50
09/27	PHAR IV SOLUTIONS	2601003	11.00
09/27	PHAR IV SOLUTIONS	2601003	26.00
09/27	PHAR IV SOLUTIONS	2601003	13.50
09/27	PHAR IV SOLUTIONS	2601003	63.50
09/27	PHARMACY	2601000	40.50
09/27	PHARMACY	2601000	11.00
09/27	PHARMACY	2601000	9.00
09/27	PHARMACY	2601000	13.50
09/27	PHARMACY	2601000	39.00
09/27	PHARMACY	2601000	3.70
09/27	PHARMACY	2601000	2.50
09/27	PACK CE 250 PROC FEE	1701018	46.00
09/27	25 NSA 5OMU PROC FEE	1701077	35.00
09/27	INFUSION PUMP	2705027	30.00
09/27	INHAL RESPIRATOR	2102015	119.00
09/27	ROOM ICU		500.00
09/28	OPER OP RM 150	1001005	521.00
09/28	LAB OCC BLOOD	1403021	16.00
09/28	LAB GENTAMYCIN TROUG	1401117	27.00
09/28	LAB DIFF	1402079	15.00
09/28	LAB RTN CULT	1405003	37.00
09/28	CARDIO ROUTINE EKG	1801001	61.00
09/28	BLD BK GROUP RH	1701002	28.00
09/28	BLD BK X MATCH	1701006	46.00
09/28	BLD BK ANTIBDY SCRN	1701004	23.00
09/28	X-RAY CHEST-BED	1501128	74.00
09/28	X-RAY CHEST-BED	1501128	74.00
09/28	PHARMACY	2601000	11.00
09/28	PHAR IV SOLUTIONS	2601003	13.50
09/28	PHAR IV SOLUTIONS	2601003	50.00
09/28	PHARMACY	2601000	3.70
09/28	PHARMACY	2601000	39.00
09/28	PHARMACY	2601000	9.00
09/28	PHARMACY	2601000	13.50
09/28	ANEST ANEST DRUGS	1103001	12.40
09/28	INHAL RESPIRATOR	2102015	119.00
09/28	OPER OP RM SUPPLY	1002000	198.00
09/28	SUCT MACHINE-CONT	2704015	22.00
09/28	DIAL SOLN 1.5-CASE	2709040	24.00
09/28	INHAL BLOOD GAS MONT	2101034	354.00
09/29	LAB CHEM-8	1401111	31.00
09/29	LAB CHEM-20	1401104	31.00
09/29	LAB AUTO BLOOD CT	1402101	17.00
09/29	LAB DIFF	1402099	15.00
09/29	LAB DIAG SM/MILL	1407002	40.00
09/29	LAB AUTO BLOOD CT	1402101	17.00
09/29	LAB AUTO BLOOD CT	1402101	17.00
09/29	LAB DIFF	1402099	15.00
09/29	LAB DIFF	1402099	15.00
09/29	LAB GENTAMYCIN TROUG	1401112	27.00
09/29	LAB SP FL CELL CT	1402018	26.00
09/29	LAB CHEM-8	1401111	31.00
09/29	LAB CHEM-8	1401111	31.00
09/29	LAB CHEM-8	1401111	31.00
09/29	LAB FUNGUS	1405008	31.00
09/29	LAB BACTERIOLOGY OUT	1405800	35.00
09/29	LAB OVA & PARASITES	1405018	31.00
09/29	LAB SM&CELL BLOCK	1407003	53.00
09/29	LAB FIBRIN QUAN	1404007	40.00
09/29	LAB COAG FIBRIN SPLT	1404018	49.00
09/29	LAB ACT PAR THROM	1404001	27.00
09/29	LAB AUTO BLOOD CT	1402101	17.00
09/29	LAB FROZEN SECT	1408004	119.00
09/29	LAB RTN CULT	1405003	37.00
09/29	BLD BK COLD AGG	1701007	18.00
09/29	BLD BK ADMIN FEE	1701028	23.00
09/29	X-RAY CHEST-BED	1501128	74.00
09/29	X-RAY ABDOMEN	1501001	58.00
09/29	PHARMACY	2601000	13.50
09/29	PHARMACY	2601000	11.00
09/29	PHAR IV SOLUTIONS	2601003	50.00
09/29	PHARMACY	2601000	39.00
09/29	PHARMACY	2601000	3.70
09/29	ISOLATION GLOVES-BOX	2709025	7.00
09/29	HEEL-ELBOW PROTECTOR	2706025	9.00
09/29	HEEL-ELBOW PROTECTOR	2706025	9.00
09/29	DIAL-PERID KIT 87110	2708015	14.00
09/29	DIAL SOLN 1.5 CASE	2709040	24.00
09/29	SPECIMEN MUCUS TRAP	2709085	3.00
09/29	INHAL BLOOD GAS MONT	2101034	354.00
09/29	INHAL BLOOD GAS MONT	2101034	354.00
09/29	INHAL BLOOD GAS MONT	2101034	354.00
09/29	ROOM ICU		500.00
09/30	LAB AUTO BLOOD CT	1402101	17.00
09/30	LAB CHEM-8	1401111	31.00
09/30	LAB CHEM-8	1401111	31.00
09/30	LAB DIFF	1402099	15.00
09/30	SP HEM COAG STDY COM	1602007	239.00
09/30	SP HEMATOLOGY	1600000	49.00
09/30	SP HEM RETIC CT	1602046	17.00
09/30	SP HEM CBC	1602010	28.00
09/30	LAB BACTERIA SM	1405011	16.00
09/30	LAB ACT PAR THROM	1404001	27.00
09/30	LAB PROTH DETER	1404011	17.00
09/30	LAB FIBRIN QUAN	1404007	40.00
09/30	LAB AUTO BLOOD CT	1402101	17.00
09/30	LAB CHEM-20	1401104	31.00
09/30	LAB TBC CULT	1405014	42.00
09/30	LAB CHEM-20	1401104	31.00
09/30	LAB RTN CULT	1405003	37.00
09/30	LAB RTN CULT	1405003	37.00
09/30	BLD BK ADMIN FEE	1701028	207.00
09/30	X-RAY CHEST-BED	1501128	74.00
09/30	X-RAY CHEST-BED	1501128	74.00
09/30	PHAR IV SOLUTIONS	2601003	16.00
09/30	PHARMACY	2601000	39.00
09/30	PHAR IV SOLUTIONS	2601003	21.00
09/30	PHAR IV SOLUTIONS	2601003	16.00
09/30	PHARMACY	2601000	3.70
09/30	PHARMACY	2601000	13.50
09/30	PHARMACY	2601000	11.00
09/30	PHARMACY	2601000	2.25
09/30	PHAR IV SOLUTIONS	2601000	21.00
09/30	PHAR IV SOLUTIONS	2601000	21.00
09/30	PHAR IV SOLUTIONS	2601003	18.50
09/30	PHARMACY	2601000	2.50
09/30	PLAT CONC PROC FEE	1701014	180.00
09/30	FRSH FR PLA PROC FEE	1701019	26.00
09/30	INHAL RESPIRATOR	2102015	119.00
09/30	DRESSING SET-DISP.	2708041	7.00
09/30	VEST RESTRAINT	2709032	12.00
09/30	INHAL BLOOD GAS MONT	2101034	354.00
09/30	ROOM ICU		500.00
10/01	LAB CHEM-20	1401104	31.00
10/01	LAB CHEM-8	1401111	31.00
10/01	LAB CHEM-8	1401111	31.00
10/01	LAB CHEM-8	1401111	31.00
10/01	LAB DIFF	1402099	15.00
10/01	LAB AUTO BLOOD CT	1402101	17.00
10/01	BLD BK ADMIN FEE	1701028	23.00
10/01	X-RAY CHEST-BED	1501128	74.00
10/01	PHAR IV SOLUTIONS	2601003	37.50
10/01	PHARMACY	2601000	13.50
10/01	PHARMACY	2601000	11.00
10/01	PHARMACY	2601000	3.70
10/01	PHARMACY	2601000	31.20
10/01	PHARMACY	2601000	2.40
10/01	PHARMACY	2601000	27.20
10/01	PHAR IV SOLUTIONS	2601003	13.50
10/01	25 NSA 5OMU PROC FEE	1701077	35.00
10/01	INHAL RESPIRATOR	2102015	119.00
10/02	PHARMACY	2601000	27.20

Mrs. K___'s first week in Intensive Care ends in a flourish of blood tests. She has five Chem-8s ("lab chem-8") - tests that measure the levels of sodium, potassium, and six other chemicals in her blood. The hospital charges Mrs. K______$31 for each Chem-8. Most independent labs charge about half as much; some hospitals charge up to $60. The *New England Journal of Medicine* has said: "The clinical laboratory [is] a convenient profit center that can be used to support unrelated deficit-producing hospital operations." The Annals *of* Internal Medicine estimates that the number of clinical lab tests being done is rising 15 percent a year.

Mrs. K______has started peritoneal dialysis ("dial-perid kit 87110"). Her kidneys are failing. She is still hooked up to the respirator. She is being kept alive by what Lewis Thomas calls "halfway technologies" — "halfway" because kidney dialysis machines and respirators can support organ systems for long periods of time, but can't cure the underlying disease. Some doctors are beginning to question this practice. A recent study at the George Washington University Medical Center concluded: "Substantial medical resources are now being used in aggressive but frequently futile attempts to avoid death."

Mrs. K_____has been put in a vest restraint. Restraints are used in Intensive Care to keep patients from thrashing about or pulling their tubes out. Many ICU patients develop what is called "ICU psychosis. " They become disoriented, begin hallucinating. The condition is brought on by lack of sleep, toxic drugs, the noise of the ICU staff and machines, and pain.

Mrs. K___ has been on the respirator for six days. It is breathing for her. But there has been a problem. The tube running from the machine into her mouth and down her throat was not bringing enough oxygen to her lungs. She needed a tracheotomy ("trach care set"). The tube from the respirator is now attached directly to her trachea, through a hole cut into her neck.

This charge - for a blood product ("5 NSA 250MU proc fee") - is not covered by Mrs. K___'s Blue Cross policy. The policy also does not cover the cost of fresh blood plasma ("frsh fr pla proc fee"). These charges have been mounting. Mrs. K___ is bleeding internally.

Mrs. K___ has been in Intensive Care for two weeks. She is still running a very high fever. The doctors are still testing. Mrs. K___ has been placed on a special blanket; it is hooked up to a machine that functions like a refrigerator ("hypothermia machine"). The machine cools the blanket, and the blanket helps lower Mrs. K___'s body temperature. Should her temperature rise too high, she may suffer permanent brain damage.

Mrs. K______has undergone a gated blood-pool study ("nuc med sec/pool sty"). The doctors have "tagged" her red blood cells with a radioactive isotope. Using a camera that picks up the isotope, the doctors can watch the passage of blood through her heart. In this way, they see firsthand whether the ventricles are functioning properly—whether enough blood is getting pumped, enough oxygen is being sent through the body. First her lungs, then her kidneys. Now Mrs. K______s' heart seems to be going.

10/02	PHARMACY	2601000	27.20
10/02	PHARMACY	2601000	2.40
10/02	PHARMACY	2601000	2.50
10/02	PHARMACY	2601000	2.25
10/02	FRSH FR PLA PROC FEE	1701019	26.00
10/02	TRACH CARE SET	2705009	3.00
10/02	TRACH CARE SET	2705009	3.00
10/02	TRACH CARE SET	2705009	3.00
10/02	TRACH CARE SET	2705009	3.00
10/03	INHAL BLOOD GAS MONT	2101034	354.00
10/03	ROOM ICU		500.00
10/04	LAB CHEM-8	1401111	31.00
10/04	LAB AUTO BLOOD CT	1402101	17.00
10/04	LAB PROTH DETER	1404011	17.00
10/04	LAB DIFF	1402099	15.00
10/04	LAB ACT PAR THROM	1404001	27.00
10/04	LAB RTN URINAL	1403001	16.00
10/04	LAB RTN CULT	1405003	37.00
10/04	BLD BK ADMIN FEE	1701028	69.00
10/04	X-RAY CHEST-BED	1501128	74.00
10/04	PHAR IV SOLUTIONS	2601003	16.00
10/04	PHAR IV SOLUTIONS	2601003	11.00
10/04	PHAR IV SOLUTIONS	2601003	18.50
10/04	PHAR IV SOLUTIONS	2601003	21.00
10/04	PHARMACY	2601000	55.50
10/04	PHARMACY	2601000	31.20
10/04	PHARMACY	2601000	2.40
10/04	PHARMACY	2601000	5.00
10/04	25 NSA 50MU PROC FEE	1701077	35.00
10/04	FRSH FR PLA PROC FEE	1701019	52.00
10/04	INHAL BLOOD GAS MONT	2101034	354.00
10/04	ROOM ICU		500.00
10/05	LAB AUTO BLOOD CT	1402101	17.00
10/05	LAB DIFF	1402099	15.00
10/05	LAB CHEM-8	1401111	31.00
10/05	LAB CHEM-20	1401104	31.00
10/05	LAB CORTISOL	1401021	27.00
10/05	LAB CORTISOL	1401021	27.00
10/05	LAB RTN CULT	1405003	37.00
10/05	LAB ACT PAR THROM	1404001	27.00
10/05	LAB PROTH DETER	1404011	17.00
10/05	BLD BK ADMIN FEE	1701028	46.00
10/05	X-RAY CHEST-BED	1501128	74.00
10/05	XRAY SONOGRAM	1505012	117.00
10/05	PHAR IV SOLUTIONS	2601003	23.50
10/05	PHARMACY	2601000	2.40
10/05	PHARMACY	2601000	31.20
10/05	PHARMACY	2601000	55.50
10/05	PHARMACY	2601000	2.40
10/05	PHAR IV SOLUTIONS	2601003	50.00
10/05	PHARMACY	2601000	96.00
10/05	PHARMACY	2601000	15.00
10/05	5 NSA 250MU PROC FEE	1701074	35.00
10/05	25 NSA 50MU PROC FEE	1701077	35.00
10/05	DIALYSIS CART	2704008	70.00
10/05	INHAL BLOOD GAS MONT	2101034	354.00
10/05	ROOM ICU		500.00
10/06	LAB CHEM-20	1401104	31.00
10/06	LAB ACT PAR THROM	1404001	27.00
10/06	LAB PROTH DETER	1404011	17.00
10/06	LAB DIFF	1402099	15.00
10/06	LAB AUTO BLOOD CT	1402101	17.00
10/06	LAB CHEM-8	1401111	31.00
10/06	LAB CHEM-20	1401104	31.00
10/06	LAB BLOOD CULT	1405002	37.00
10/06	LAB BLOOD CULT	1405002	37.00
10/06	LAB PROTH DETER	1404011	17.00
10/06	LAB ACT PAR THROM	1404001	27.00
10/06	BLD BK ADMIN FEE	1701028	23.00
10/06	X-RAY CHEST-BED	1501128	74.00
10/06	X-RAY CHEST-BED	1501128	74.00
10/06	PHAR IV SOLUTIONS	2601003	26.00
10/06	PHARMACY	2601000	2.40
10/06	PHARMACY	2601000	55.50
10/06	PHARMACY	2601000	31.20
10/06	PHAR IV SOLUTIONS	2601003	99.00
10/06	PHARMACY	2601000	249.60
10/06	PHAR IV SOLUTIONS	2601003	13.50
10/06	PHAR IV SOLUTIONS	2601003	37.50
10/06	PHARMACY	2601000	2.40
10/06	25 NSA 50MU PROC FEE	1701077	35.00
10/06	INFUSION PUMP	2705027	30.00
10/06	DIAL SOLN 1.5-CASE	2709040	24.00
10/06	HYPOTHERMIA MACHINE	2704006	25.00
10/06	ROOM ICU		500.00
10/07	LAB ACT PAR THROM	1404001	27.00
10/07	LAB PROTH DETER	1404011	17.00
10/07	LAB AUTO BLOOD CT	1402101	17.00
10/07	LAB DIFF	1402099	15.00
10/07	LAB CHEM-8	1401111	31.00
10/07	LAB CHEM-8	1401111	31.00
10/07	LAB CHEM-20	1401104	31.00
10/07	LAB CHEM-8	1401111	31.00
10/07	LAB CHEM-20	1401104	31.00
10/07	LAB CHEM-8	1401111	31.00
10/08	PHARMACY	2601000	55.50
10/08	PHARMACY	2601000	31.20
10/08	PHAR IV SOLUTIONS	2601003	18.50
10/08	PHARMACY	2601000	5.00
10/08	PHARMACY	2601000	5.00
10/08	PHARMACY	2601000	5.00
10/08	PHARMACY	2601000	62.00
10/08	INHAL RESPIRATOR	2102015	119.00
10/08	ISOLATION GLOVES-BOX	2709025	7.00
10/08	DIAL SOLN 1.5-CASE	2709040	24.00
10/08	INHAL BLOOD GAS MONT	2101034	354.00
10/08	ROOM ICU		500.00
10/09	LAB ACT PAR THROM	1404001	27.00
10/09	LAB PROTH DETER	1404011	17.00
10/10	LAB ACT PAR THROM	1404001	27.00
10/10	CARDIO ROUTINE EKG	1801001	61.00
10/10	X-RAY CHEST-BED	1501128	74.00
10/11	LAB CHEM-8	1401111	31.00
10/11	LAB CHEM-8	1401111	31.00
10/11	ROOM ICU		500.00
10/12	PHAR IV SOLUTIONS	2601003	37.50
10/12	PHARMACY	2601000	2.40
10/12	25 NSA 50MU PROC FEE	1701077	70.00
10/12	INHAL RESPIRATOR	2101015	119.00
10/12	INHAL RESPIRATOR	2102015	119.00
10/12	DIAL SOLN 1.5-CASE	2709040	24.00
10/12	PLASTIC TRACH TUBE	2705007	26.00
10/12	PLASTIC TRACH TUBE	2705007	26.00
10/12	DIALYSIS CART	2704008	70.00
10/12	INHAL BLOOD GAS MONT	2101034	354.00
10/12	ROOM ICU		500.00
10/13	LAB DIFF	1402099	15.00
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10/13	LAB PROTH DETER	1404011	17.00
10/13	LAB ACT PAR THROM	1404001	27.00
10/13	LAB CHEM-20	1401104	31.00
10/13	LAB CHEM-8	1401111	31.00
10/13	LAB CHEM-8	1401111	31.00
10/13	LAB CHEM-8	1401111	31.00
10/13	LAB CHEM-8	1401111	31.00
10/13	LAB DIFF	1402099	15.00
10/13	LAB RTN CULT	1405003	37.00
10/13	LAB AUTO BLOOD CT	1402101	17.00
10/13	LAB BACTERIA SM	1405011	16.00
10/13	LAB RTN CULT	1405003	37.00
10/13	LAB RTN CULT	1405003	37.00
10/13	NUC MED SEC/POOL STY	3001021	170.00
10/13	BLD BK ADMIN FEE	1701028	23.00
10/13	BLD BK ANTIBDY SCRN	1701004	23.00
10/13	BLD BK DIR COOMBS	1701031	18.00
10/13	X-RAY CHEST-BED	1501128	74.00
10/13	PHARMACY	2601000	2.40
10/13	PHAR IV SOLUTIONS	2601003	26.00
10/13	PHAR IV SOLUTIONS	2601003	26.00
10/13	PHARMACY	2601000	31.20
10/13	PHARMACY	2601000	55.50
10/13	PHARMACY	2601000	14.50
10/13	PHARMACY	2601000	2.40
10/13	PHAR IV SOLUTIONS	2601003	21.00
10/14	PACK CE 250 PROC FEE	1701013	92.00
10/14	25 NSA 50MU PROC FEE	1701077	35.00
10/14	INHAL RESPIRATOR	2102015	119.00
10/14	INHAL BLOOD GAS MONT	2101034	354.00
10/14	ROOM ICU		500.00
10/15	LAB CHEM-8	1401111	31.00
10/15	LAB CHEM-8	1401111	31.00
10/15	LAB CHEM-20	1401104	31.00
10/15	LAB INDIA INK	1405009	17.00
10/15	LAB FUNGUS	1405008	31.00
10/15	LAB TBC CULT	1405014	42.00
10/15	LAB HETER MONO	1406005	25.00
10/15	LAB UR ELECTROPHORES	1403007	26.00
10/15	LAB CHEM-8	1401111	31.00
10/15	LAB CHEM-8	1401111	31.00
10/15	LAB SP FL CELL CT	1402018	26.00
10/15	LAB CHEM-8	1401111	31.00
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10/15	LAB SP FL PROT	1401057	27.00
10/15	LAB MAGNES	1401042	27.00
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10/16	LAB CHEM-8	1401111	31.00
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10/16	LAB AUTO BLOOD CT	1402101	17.00
10/16	LAB RTN CULT	1405003	37.00
10/16	LAB ANTIBIOT SENS	1405001	40.00
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10/16	PHARMACY	2601000	14.50
10/16	PHARMACY	2601000	2.40
10/16	PHARMACY	2601000	31.20
10/16	PHARMACY	2601000	2.40
10/16	PHARMACY	2601000	2.40
10/16	PHARMACY	2601000	24.00
10/16	PHARMACY	2601000	297.00
10/16	INHAL RESPIRATOR	2102015	119.00
10/16	HYPOTHERMIA MACHINE	2704006	25.00
10/16	ISOLATION GLOVES-BOX	2709025	7.00
10/16	ISOLATION GLOVES-BOX	2709025	7.00
10/16	INHAL BLOOD GAS MONT	2101034	354.00
10/16	ROOM ICU		500.00
10/17	TELEPHONE CHARGE	0000002	48.00
10/17	LAB ACT PAR THROM	1404001	27.00
10/17	LAB CHEM-8	1401111	31.00
10/17	LAB CHEM-8	1401111	31.00
10/17	LAB CHEM-20	1401104	31.00
10/17	LAB CHEM-8	1401111	31.00
10/17	LAB PROTH DETER	1404011	17.00
10/17	LAB CHEM-20	1401104	31.00
10/17	X-RAY CHEST-BED	1501128	74.00
10/17	PHARMACY	2601000	55.50
10/17	PHARMACY	2601000	31.20
10/17	PHARMACY	2601000	2.40
10/17	PHARMACY	2601000	25.00
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10/17	PHARMACY	2601000	2.40
10/17	PHARMACY	2601000	14.50
10/17	PHARMACY	2601000	.80
10/17	PHARMACY	2601000	2.25
10/17	PHARMACY	2601000	2.40
10/17	PHAR IV SOLUTIONS	2601003	13.50
10/17	PHAR IV SOLUTIONS	2601003	37.50
10/17	PHAR IV SOLUTIONS	2601003	16.00
10/17	PHAR IV SOLUTIONS	2601003	21.00
10/17	PHAR IV SOLUTIONS	2601003	13.50
10/17	PHAR IV SOLUTIONS	2601003	16.00
10/17	PHAR IV SOLUTIONS	2601003	16.00
10/17	PHAR IV SOLUTIONS	2601003	16.00
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10/17	PHAR IV SOLUTIONS	2601003	37.50
10/17	PHAR IV SOLUTIONS	2601003	37.50
10/17	PHAR IV SOLUTIONS	2601003	37.50
10/17	PHAR IV SOLUTIONS	2601003	16.00
10/18	PLAT CONC PROC FEE	1701014	117.50
10/18	25 NSA 50MU PROC FEE	1701077	35.00
10/18	INHAL RESPIRATOR	2102015	119.00
10/18	INHAL BLOOD GASES	2101006	119.00
10/18	INHAL BLOOD GASES	2101006	119.00

SUMMARY OF CHARGES

OPERATING ROOM	521.00
DRUGS	6364.70
BLOOD SERV & FRACT	1389.50
LABORATORY	11201.00
X-RAY	2870.00
SUPPLIES	3698.00
EKG, EEG, ETC.	366.00
THERAPY	8734.00
MICS NON COVERED	167.00
R&C IN.CARE 24 DAYS 500.00/DAY	12000.00
SUB-TOTAL OF CHARGES	47311.20
TOTAL	47311.20

Mrs. K___'s fourth week in the hospital begins with a spinal tap. Using a long needle, a doctor drains fluid from her spinal cord. The fluid is sent to the lab for about a dozen tests ("lab sp fl cell et"). A spinal tap is performed when a patient has what are called "neurological signs." Partial paralysis is one such sign, loss of consciousness another. When doctors order a spinal tap, they suspect brain disease.

Weeks of halfway technology have given the doctors time for testing. The doctors may even have diagnosed what is wrong with Mrs. K_____; it is hard to say. But the ICU and its technology have not given them the ability to cure her. Now the heart, which has been failing, gives out. Cardiac arrest. There is a burst of activity. Bicarbonate, epinephrine, and other drugs ("pharmacy") are administered. Thirteen bottles of intravenous solution ("phar iv solutions") are poured in.

Mrs. K___'s last minutes are recorded on the various ICU monitors. The level of oxygen in her blood falls. She dies.

Mrs. K___'s bottom line. Total cost of twenty-six days in the hospital, nearly all this time in Intensive Care: $47,311.20. Of this, Blue Cross will pay $41,933.87. The doctors' bills, not covered by hospitalization insurance, probably come to thousands of dollars more. Perhaps Mrs. K_______had Blue Shield, which covers doctors' fees. In 1982, the last year for which figures are available, Americans spent $322 billion on health care. Of this, $135.5 billion was spent on hospital care. There were 56,241 ICU beds in 1982 like the one Mrs. K___ was kept alive in, and about $27 billion was spent for their use. That represented nearly one percent of the gross national product.

All elements in the map at right — contours, rivers, roads, names — are at the same visual level with equal values, equal texture, equal color, and even nearly equal shape. An undifferentiated, unlayered surface results, jumbled up, blurry, incoherent, chaotic with unintentional optical art. What we have here is a failure to communicate.

Simla, India (U.S. Army map series U 502, NH 43-4, 1954), based on the Survey of India, 1921-1943.

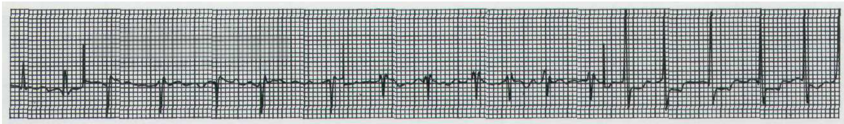
Far more detailed than the perfect jumble, this map below separates and layers information by means of distinctions in shape, value (light to dark), size, and especially color. The negative areas are also informative;

Tokyo Prefecture. Musashino, Ueno Park, Kurumazaka area (Tokyo, 1884).

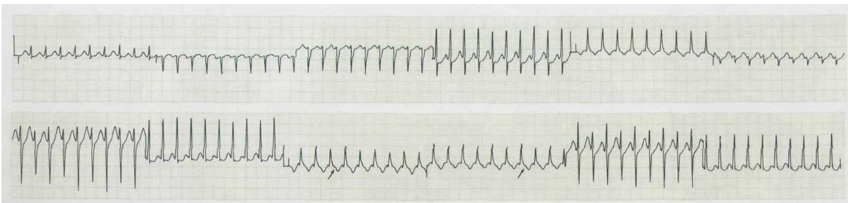
light strips formed by the grid of buildings identify roads and paths. The water symbol is a blue field, further differentiated from other color fields by a gentle fading away from each outlined edge. Shown against a dull background rather than bright white, these colors remain both calm and distinctive, avoiding clutter. The map exemplifies the "first rule of color composition" of the illustrious Swiss cartographer, Eduard Imhof:

> Pure, bright or very strong colors have loud, unbearable effects when they stand unrelieved over large areas adjacent to each other, but extraordinary effects can be achieved when they are used sparingly on or between dull background tones. "Noise is not music . . . only on a quiet background can a colorful theme be constructed," claims Windisch.[3]

[3] Eduard Imhof, *Cartographic Relief Presentation* (Berlin, 1982), edited and translated by H. J. Steward from Imhof's *Kartographische Geländedarstellung* (Berlin, 1965), p. 72. The internal quotation is from H. Windisch, *Schule der Farbenphotographie* (Scebruck, 6th edition, 1958).



Signal and background compete above, as an electrocardiogram trace-line becomes caught up in a thick grid. Below, the screened-down grid stays behind traces from each of 12 monitoring leads:[4]

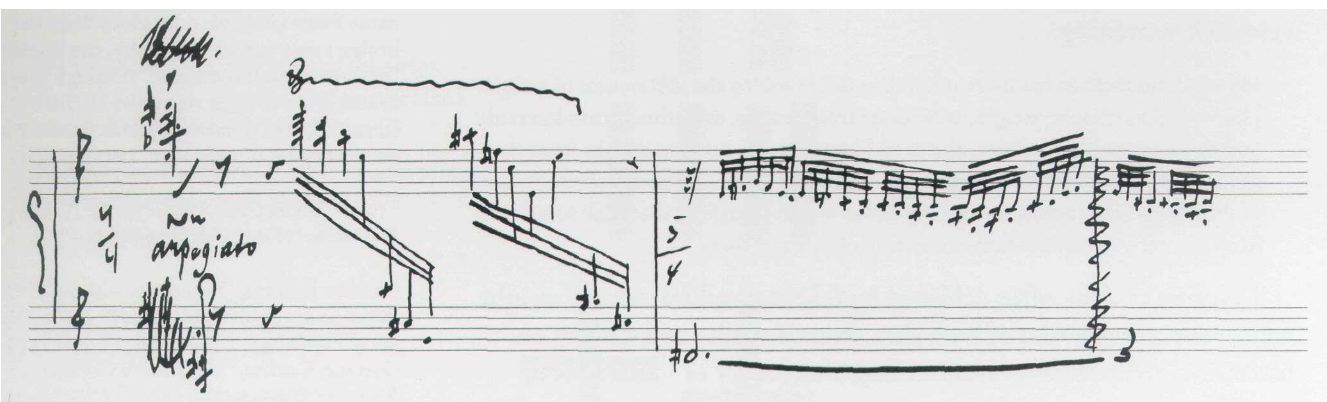


[4] The preferred example is redrawn from J. Marcus Wharton and Nora Goldschlager, *Interpreting Cardiac Dysrhythmias* (Oradell, New Jersey, 1987), p. 123. Color also layers, as a gray grid calibrates this signal of ventricular fibrillation, a final collapse of the

heart, with only a disorganized rhythm remaining. A similar trace can result from recording artifacts such as a loose monitoring wire; however, one textbook dryly notes, "As the patient will usually have lost consciousness by the time you have realized that it is not just due to a loose connection, diagnosis is easy." John R. Hampton, *The ECG Made Easy* (Edinburgh, 1986), p. 66.

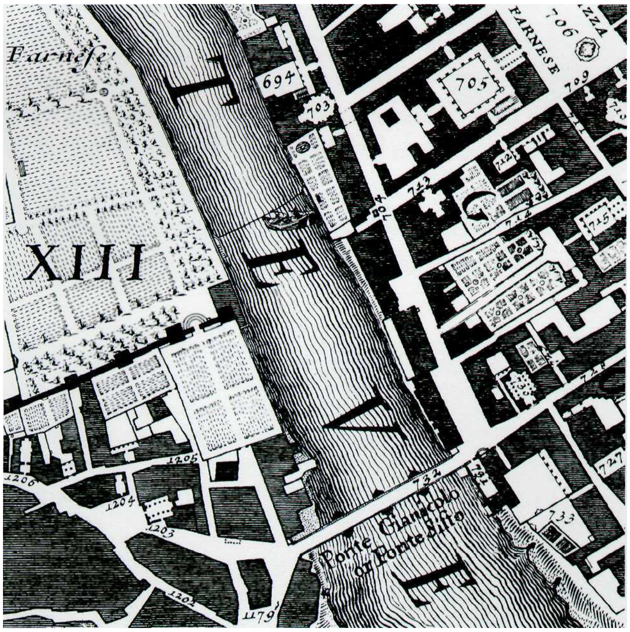
Similarly for music notation, some staff paper is better than others:

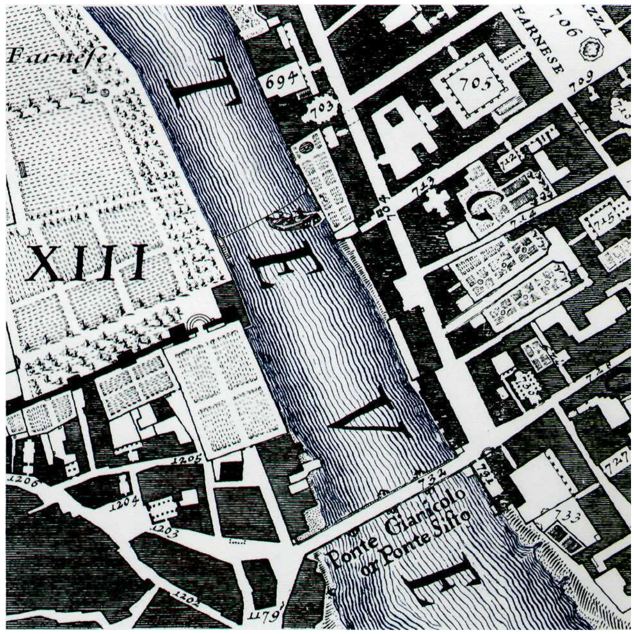
In Stravinsky's sketchbook for *Sacre du printemps,* a grid quietly but clearly and precisely locates the music. Gray grids almost always work well and, with a delicate line, may promote more accurate data reading



and reconstruction than a heavy grid. Dark grid lines are chartjunk. When a graphic serves as a look-up table (rare indeed), then a grid may help with reading and interpolation. But even then the grid should be muted relative to the data. Often ready-made graph paper comes with darkly printed lines. The reverse imprinted side should be used, for then lines show through faintly and do not clutter the data. If the paper is heavily gridded on both sides, throw it out.

Igor Strawinsky, *Sacre-Skizzenbuch,* p. 135, top; Paul Sacher Stiftung, Kunstmuseum Basel, and in Hans Oesch, "Im Schatten des *Sacre du printemps* Beobachtungen zu den Trois poesies de la lyrique japonaise, einem Schlüsselwerk von Igor Strawinsky," *Komponisten des 20..Jahrhunderts in der Paul Sacher Stiftung* (Basel, 1986), p. 100.

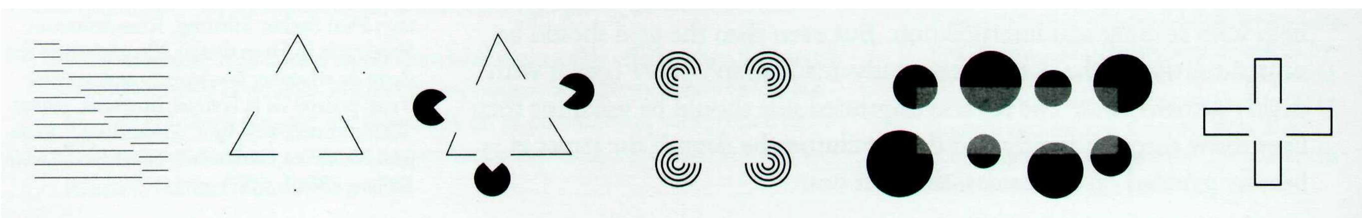




In the masterly 1748 Nolli map of Rome, the river's heavy inking activates what should be a visually tranquil area, causing bridge names and a little boat to vibrate in a moire prison, albeit a quiet one. Muting the river encoding calms vibration and brings names and other details forward, while retaining a symbolism of rippling water.[5] This redesign and others that we have seen are visual equivalents of Italo Calvino's approach to writing:

> My working method has more often than not involved the subtraction of weight. I have tried to remove weight, sometimes from people, sometimes from heavenly bodies, sometimes from cities; above all I have tried to remove weight from the structure of stories and from language. . . . Maybe I was only then becoming aware of the weight, the inertia, the opacity of the world — qualities that stick to writing from the start, unless one finds some way of evading them.[6]

Layering of data, often achieved by felicitous subtraction of weight, enhances representation of both data dimensionality and density on flatland. Usually this involves creating a hierarchy of visual effects, possibly matching an ordering of information content. Small, modest design moves can yield decisive visual results, as in these intriguing demonstrations of the illusory borders of subjective contours:



[5] Giambattista Nolli, *Pianta Grande di Roma* (Rome, 1748; from a facsimile edition by J. H. Aronson, Highmount, New York, 1984). Note the seemingly English word "or" in the names under the bridge, a result of the 18th-century custom of contracting the Italian *ora*, meaning *now, at this time, currently.* On his map, Nolli cites first the old name *Ponte Gianicolo or[a] Ponte Sisto* (the bridge's new name). Ironically, the English "or" works in this context, although the meaning is not quite right. See Barbara Reynolds, *The Cambridge Italian Dictionary, Italian-English* (Cambridge, 1962), p. 521.

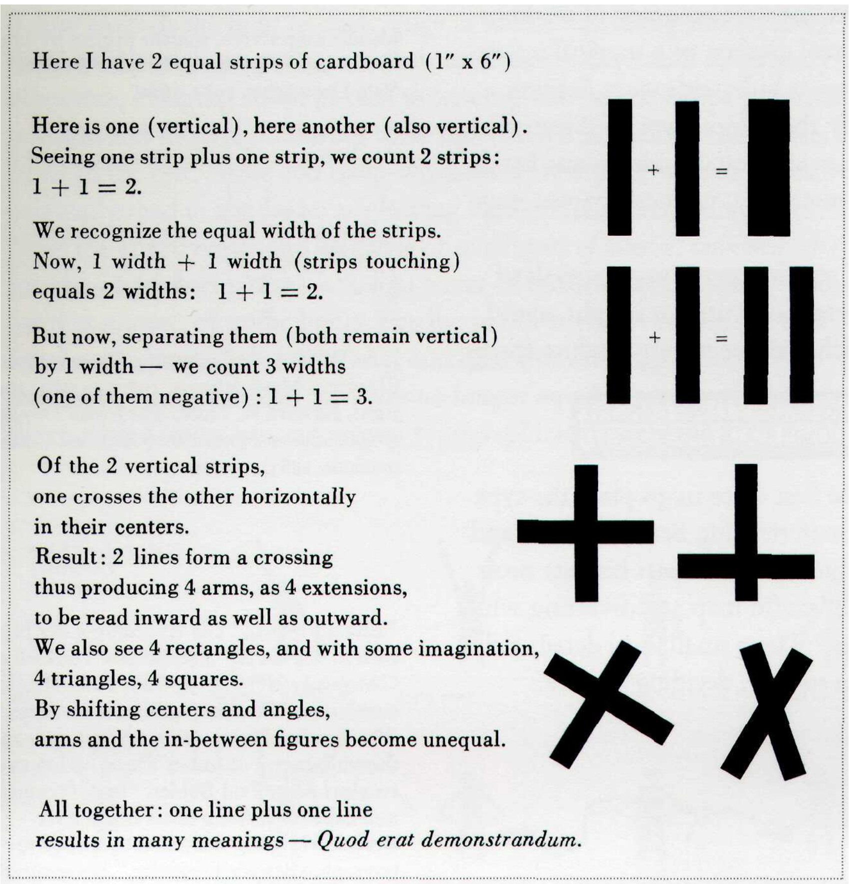
[6] Italo Calvino, *Six Memos for the Next Millennium* (Cambridge, 1988), pp. 3-4.

Gaetano Kanizsa, "Contours without Gradients or Cognitive Contours?" *Italian Journal of Psychology,* 1 (April 1974), 93-112; and Gaetano Kanizsa, "Subjective Contours," *Scientific American,* 234 (April 1976), 48-52.

Visual activation of negative areas of white space in these exhibits illustrates *the endlessly contextual and interactive nature of visual elements.* This idea is captured in a fundamental principle of information design: *1 + 1 = 3 or more*. In the simplest case, when we draw two black lines, a third visual activity results, a bright white path between hues (note that this path appears even to have an angled end). And a complexity

of marks generates an exponential complexity of negative shapes. *Most of the time, that surplus visual activity is non-information, noise, and clutter.*[7] This two-step logic — recognition of 1 + 1 = 3 effects and the consideration that they generate noise — provides a valuable guide for refining and editing designs, for graphical reasoning, for subtraction of weight.[8]

In a little-known essay on 1 + 1 = 3 effects, Josef Albers conducts the demonstrations below, a visually sensitive and artistic approach to the cognitive contours of perceptual psychologists. Albers, seeing area and surface rather than border and edge, escapes the preoccupying magic of optical illusions to conceive a broad idea of negative space activation:



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.

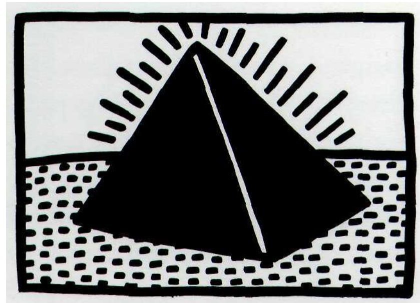
We recognize the equal width of the strips.
Now, 1 width + 1 width (strips touching)
equals 2 widths: 1 + 1 = 2.

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.*

Josef Albers, "One Plus One Equals Three or More: Factual Facts and Actual Facts," in Albers, *Search Versus Re-Search* (Hartford, 1969), pp. 17-18.

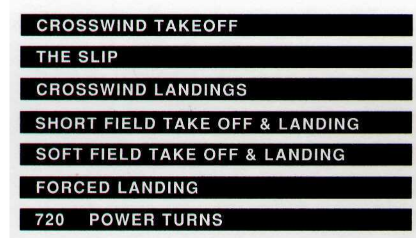


Keith Haring, Untitled 4/29/82, sumi ink on paper. © 1992 Estate of Keith Haring.

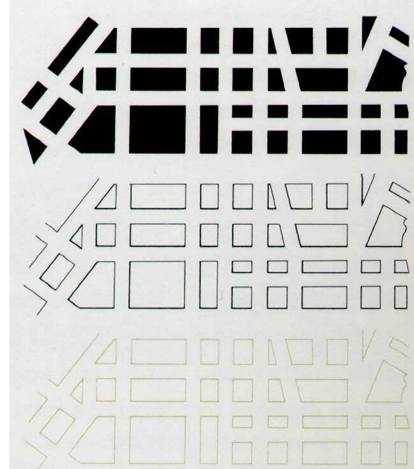
[7] Rare exceptions are the Turgot-Bretez map of Paris and the Nolli map of Rome: streets, absent of ink, are defined — tersely, clearly, and precisely — by the surrounding ink of blocks and buildings, creating subjective contours.

[8] Note the additional 1 + 1 = 3 effects, on this page, as the interaction between the examples and the surrounding type enlivens the white space, forming shapes, profiles, and paths. These reverberations are vivid because our examples are printed in black; strong light / dark contrasts accentuate the clutter of 1 + 1 = 3 or more.

Stumbling over 1 + 1 = 3 has produced perhaps the worst index ever designed, a rare perfect failure. The preface to this guide for flying small aircraft says, "This manual is primarily intended for use during actual flight instruction." Imagine now noisy vibration in a plane as we search through this visually vibrating list, looking for, say, an entry on "forced landing" ... and the index turns out to have no page numbers. Only a small segment of the unbearable original is shown.

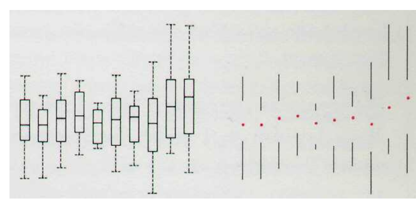

CROSSWIND TAKEOFF
THE SLIP
CROSSWIND LANDINGS
SHORT FIELD TAKE OFF & LANDING
SOFT FIELD TAKE OFF & LANDING
FORCED LANDING
720 POWER TURNS

The noise of 1 + 1 = 3 is directly proportional to the contrast in value (light/dark) between figure and ground. On white backgrounds, therefore, a varying range of lighter colors will minimize incidental clutter. Three maps at right show these tactics in action. In the first, the bold shapes promote vibration all over; and with only nameless streets down on paper, this map is already in visual trouble. At center, thinning two sides of each block results in every street bordered by one thick *and* one thin line, thus deflecting 1 + 1 = 3 effects (the thin lines, like gray lines, are *visually* light in value). On the bottom map, gray establishes serene, motionless edges - an arrangement that will easily accommodate additional geographic detail.



Middle map above, student project by Jon Wertheimer, Studies in Graphic Design, Yale University, 1985-1986.

Careful visual editing diminishes 1 + 1 = 3 clutter. These are not trivial cosmetic matters, for signal enhancement through noise reduction can reduce viewer fatigue as well as improve accuracy of readings from a computer interface, a flight-control display, or a medical instrument. Clarity is not everything, but there is little without it. Editing this statistical graph (showing variability about local averages) remedies the visual clutter induced by parallel lines and equal-width white bands. The redesign, at far right, sweeps the noise away, with color spots now smartly tracking the path of averages.

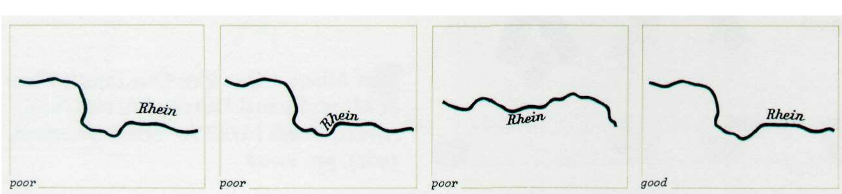


John W. Tukey, *Exploratory Data Analysis* (Reading, Massachusetts, 1977), p. 269; and, right, Edward R. Tufte, *The Visual Display of Quantitative Information* (Cheshire, Connecticut, 1983), p. 125.

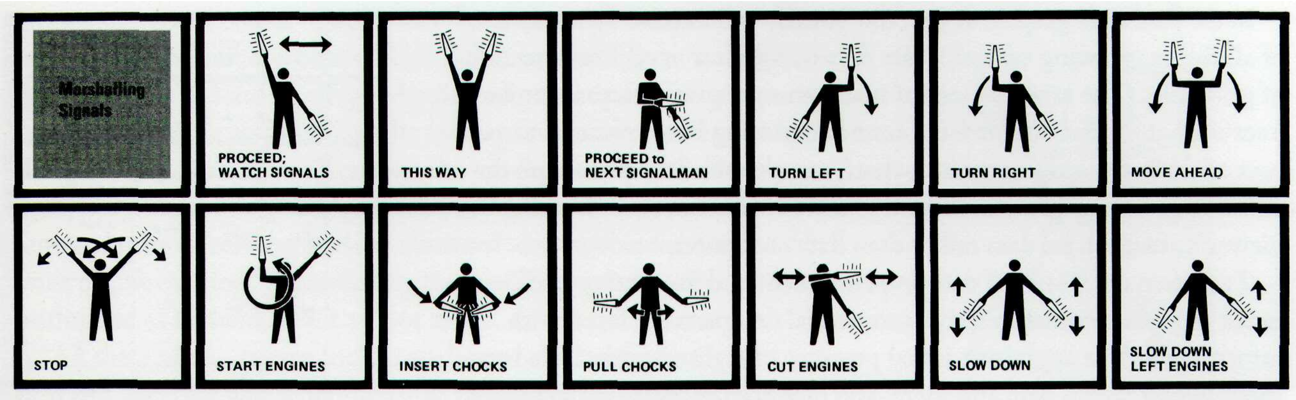
Harmonizing text and line-drawing requires sensitive appraisals of prolific interaction effects. Unless deliberate obscurity is sought, avoid surrounding words by little boxes, which activate negative white spaces

SURGEON GENERAL'S WARNING: SMOKING CAUSES LUNG CANCER, HEART DISEASE, EMPHYSEMA, AND MAY COMPLICATE PREGNANCY

between word and box. And below, the first three maps place the type poorly, with an awkward white stripe materializing between name and river. Type from above adjusts to graphics better, in part because most words have fewer descenders than ascenders (in map 3, a diverting white shape is formed by the ascending letters).[9] These small local details will promptly accumulate on the entire map surface, deciding quality.



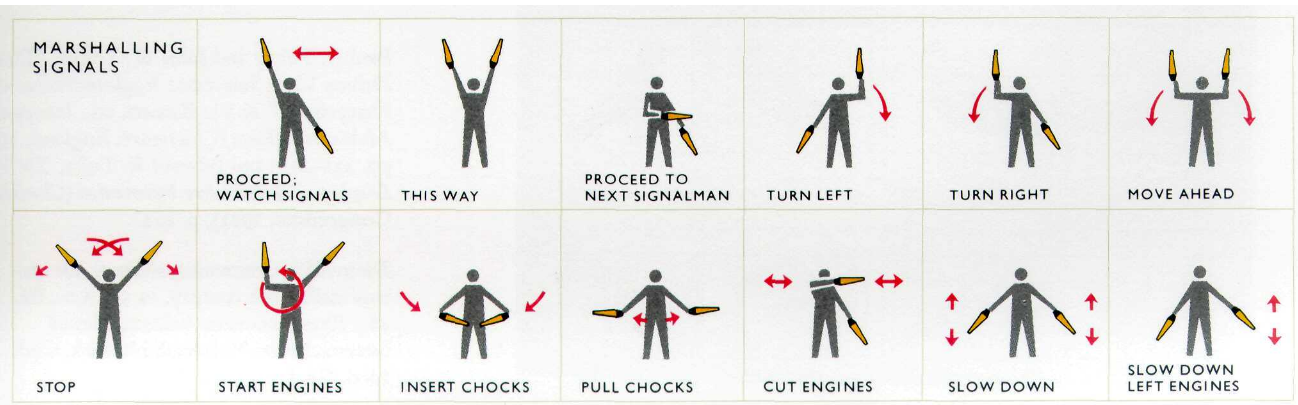
[9] Eduard Imhof, "Die Anordnung der Namen in der Karte," *International Yearbook of Cartography*, 2 (1962), 93-129; and, in English translation, "Positioning Names on Maps," *The American Cartographer*, 2 (1975), 128-144; showing here 4 of Imhof's total of 106 examples! Also, Paul Bühler, "Schriftformen und Schrifterstellung unter besonderer Berücksichtigung der schweizerischen topographischen Kartenwerke," *International Yearbook of Cartography*, 1 (1961), 153-181.



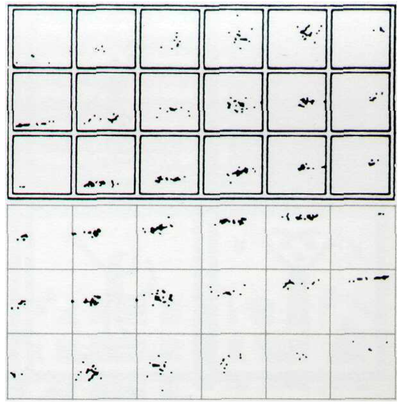
This array above, an information prison, employs a narrow range of strong shapes. Grid, silhouette, and type compete at the same nervous visual level. Too loud and too similar. Thick bars of grid boxes generate little paths around both type and silhouette by exciting the negative white space: 1 + 1 = 3, all over again. Why should the trivial task of dividing up the already free-standing elements become the dominant statement of the entire display?

To direct attention toward the information at hand, the revision below extends the light to dark range of color, separating and layering the data in rough proportion to their relevance. Gray calms a contrasty silhouette, bringing about in turn more emphasis on the lamps and their position and motion. Coloring these lights helps to separate the signals from all the rest. Some 460 lamp-whiskers were erased, whiskers which originally read in confusion as glowing light and also trembling motion. Note the effectiveness and elegance *of small spots of intense, saturated color* for carrying information—a design secret of classical cartography[10] and, for that matter, of traffic lights. Finally, in our revised version, the type for the title (upper left corner) has emerged from its foggy closet. Also the labels, now set in Gill Sans, are no longer equal in visual weight to the motion arrows, among several typographical refinements.

[10] "If one limits strong, heavy, rich, and solid colors to the small areas of extremes, then expressive and beautiful colored area patterns occur... Large area background or base-colors do their work most quietly, allowing the smaller, bright areas to stand out most vividly, if the former are muted, grayish or neutral." Eduard Imhof, *Cartographic Relief Presentation* (Berlin, 1982), edited and translated by H. J. Steward from Imhof's *Kartographische Geländedarstellung* (Berlin, 1965), p. 72. On visual issues and map-making, see essays by Samuel Y. Edgerton, Jr., Svetlana Alpers, Juergen Schulz, Ulla Ehrensvärd, James A. Welu, and David Woodward, in Woodward, ed., *Art and Cartography* (Chicago, 1987).



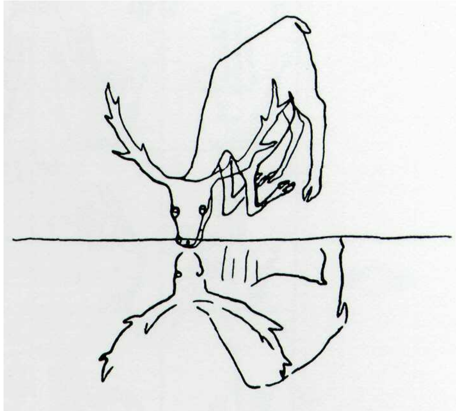
In the statistical graphic at top, the visually most active elements are, of all things, glowing optical white dots that appear at each intersection of grid hues. (The arrangement of many computer interfaces is similarly overwrought.) The doubled-up, tremor-inducing lines consume 18 percent of this technically ingenious chart, a multi-window plot. Here the redrawing, in ungrid style, eliminates the visual noise, concentrating our viewer's attention on data rather than data containers.



Too often epidemics of data-imprisonment and decorative gridding break out when contemporary commercial designers are faced with information. The aggressive visual presence of stylized grids, little boxes surrounding words here and there, and cadenced accents—all so empty of content, irrelevant—becomes the only way you can tell if something has been "designed". At any rate, the self-important grid is for the birds, providing only a nice place to perch:

Paul A. Tukey and John W. Tukey, "Data-Driven View Selection; Agglomeration and Sharpening," in Vic Barnett, ed., *Interpreting Multivariate Data* (Chichester, England, 1981), pp. 231-232; and Edward R. Tufte, *The Visual Display of Quantitative Information* (Cheshire, Connecticut, 1983), p. 114.

Dioscorides (Constantinopolitanus), De materia medica, 6th century, ca 512 A.D., fol. 483. Illumination on vellum, Vienna österreichische Nationalbibliothek, Cod. Med. Gr. I.



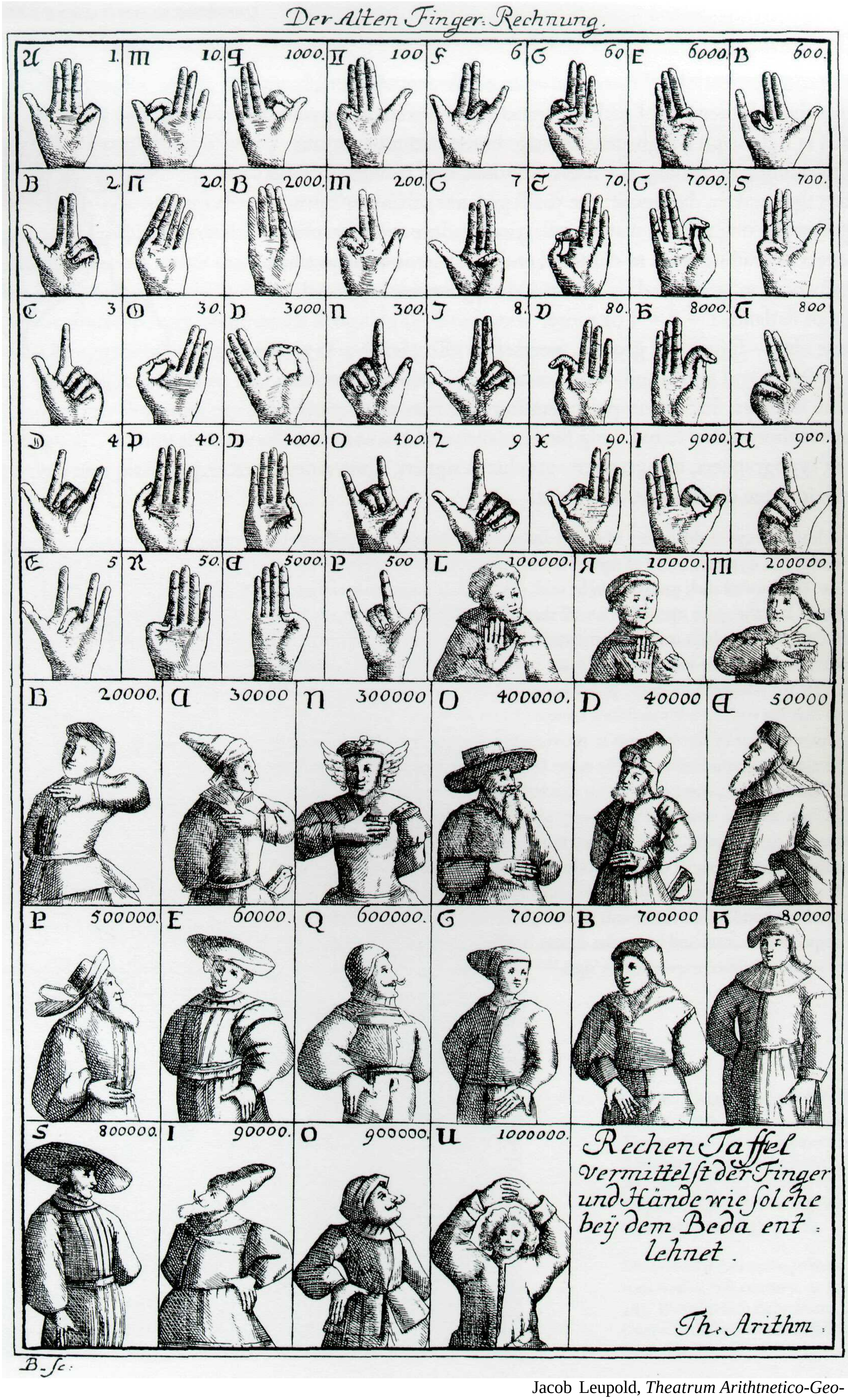
Fables of Aesop, According to Sir Roger L'Estrange with drawings by Alexander Calder (Paris, 1931; New York, 1967), p. 1.

INFORMATION consists of *differences that make a difference.* A fruitful method for the enforcement of such differences is to layer and separate data, much as is done on a high-density map. In representing various layers of meaning and reading, the most economical of means can yield distinctions that make a difference: the small gestures of Calder's pen easily separate the stag and his watery reflection. Failure to differentiate among layers of reading leads to cluttered and incoherent displays filled with disinformation, generated by the unrelenting interactive visual arithmetic of flatland, 1 + 1 = 3 or more.

All these ideas—figure and ground, interaction effects, 1 + 1 = 3 or more, layering and separation - have compelling consequences for information displays. Such concepts (operating under an assortment of names) are thoroughly tested, long familiar the world over in the flatlands of typographers, calligraphers, graphic designers, illustrators, artists, and, in three dimensions, architects:

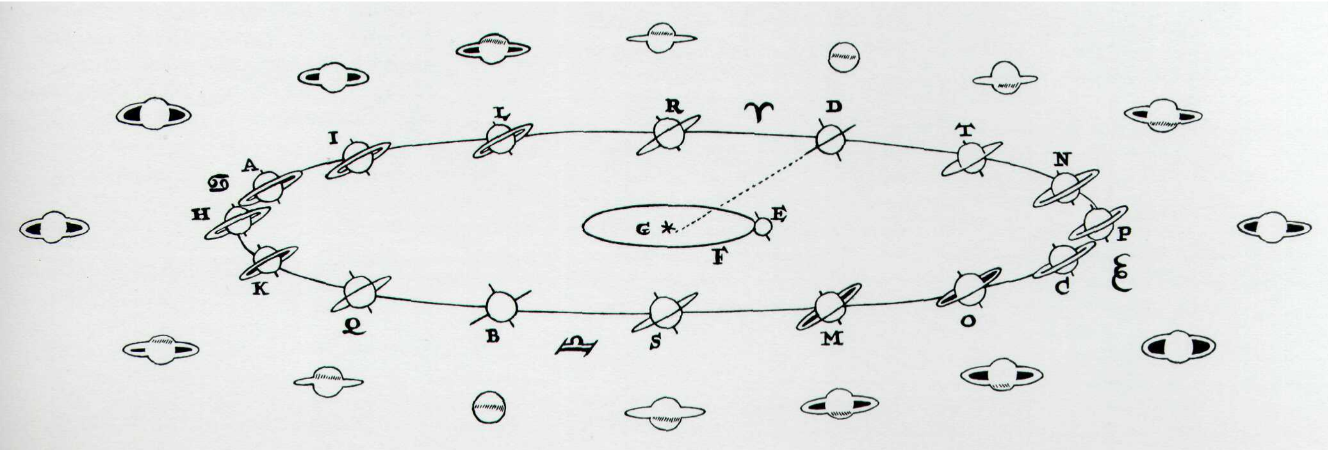
> In every clear concept of the nature of vision and in every healthy approach to the spatial world, this dynamic unity of figure and background has been clearly understood. Lao Tse showed such grasp when he said: "A vessel is useful only through its emptiness. It is the space opened in a wall that serves as a window. Thus it is the nonexistent in things which makes them serviceable." Eastern visual culture has a deep understanding of the role of empty space in the image. Chinese and Japanese painters have the admirable courage to leave empty large paths of their picture — surface so that the surface is divided into unequal intervals which, through their spacing, force the eye of the spectator to movements of varying velocity in following up relationships, and thus create the unity by the greatest possible variation of surface. Chinese and Japanese calligraphy also have a sound respect for the white interval. Characters are written in imaginary squares, the blank areas of which are given as much consideration as the graphic units, the strokes. Written or printed communications are living or dead depending upon the organization of their blank spaces. A single character gains clarity and meaning by an orderly relationship of the space background which surrounds it. The greater the variety and distinction among respective background units, the clearer becomes the comprehension of a character as an individual expression or sign.[11]

[11] Gyorgy Kepes, *The Language of Vision* (Chicago, 1948).



Jacob Leupold, *Theatrum Arithtnetico-Geometricum* (Leipzig, 1727), section 4, tab. I.

4 *Small Multiples*



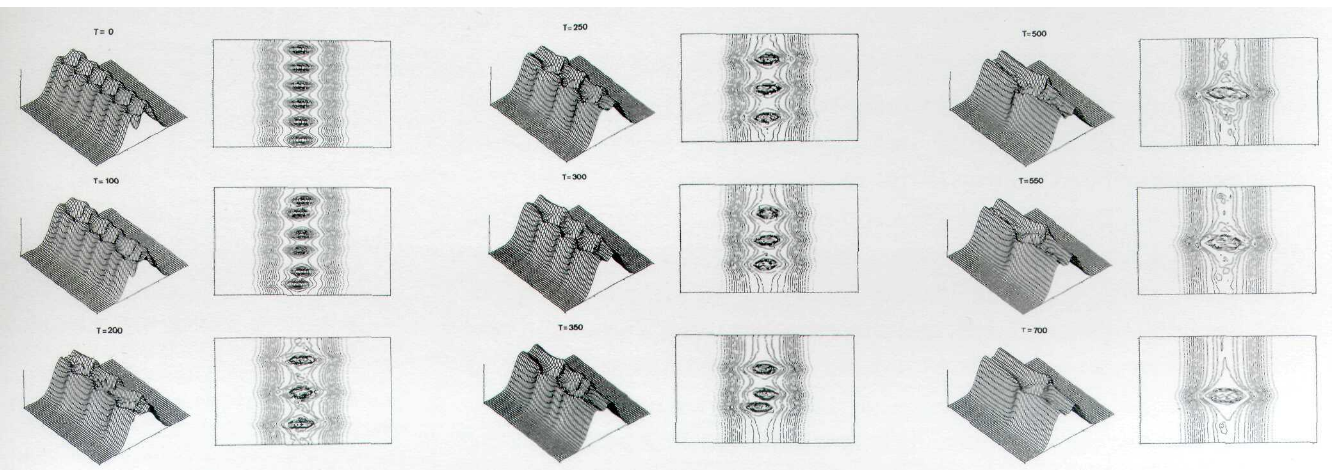
IN this splendid 1659 drawing by Christiaan Huygens, the inner ellipse traces Earth's yearly journey around the Sun; the larger ellipse shows Saturn's orbit, viewed from the heavens. The outermost images depict Saturn as seen through telescopes located on Earth. All told, we have 32 Saturns, at different locations in three-space and from the perspective of two different observers—a superior *small multiple* design.

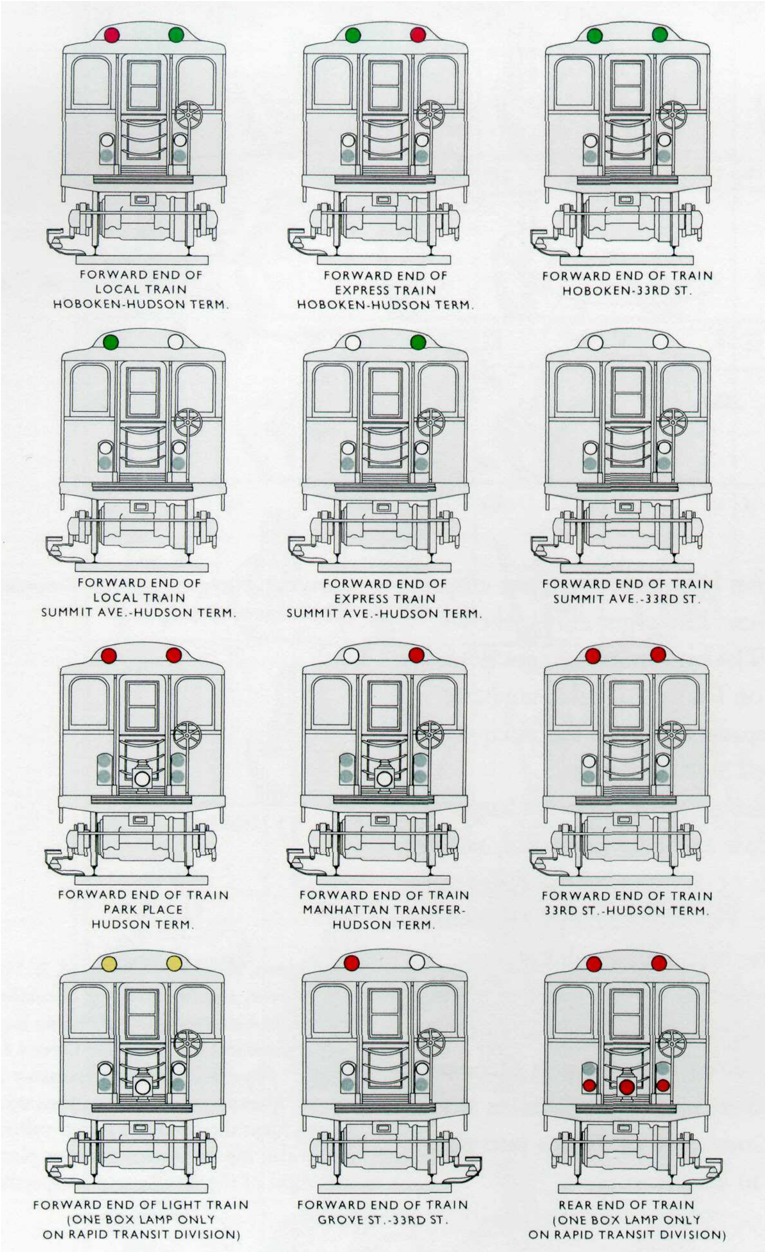
Christiaan Huygens, *Systema Saturnium* (The Hague, 1659), p. 55.

At the heart of quantitative reasoning is a single question: *Compared to what?* Small multiple designs, multivariate and data bountiful, answer directly by visually enforcing comparisons of changes, of the differences among objects, of the scope of alternatives. For a wide range of problems in data presentation, small multiples are the best design solution.

Illustrations of postage-stamp size are indexed by category or a label, sequenced over time like the frames of a movie, or ordered by a quantitative variable not used in the single image itself. Information slices are positioned within the eyespan, so that viewers make comparisons at a glance — uninterrupted visual reasoning. Constancy of design puts the emphasis on changes in data, not changes in data frames.

A. Ghizzo, B. Izrar, P. Betrand, E. Fijalkow, M. R. Feix, and M. Shoucri, "Stability of Bernstein-Greene-Kruskal Plasma Equilibria: Numerical Experiments Over a Long Time," *Physics of Fluids*, 31 (January 1988), 72-82. Viewing these illustrations upside down turns the mountains into valleys. Note also the two-space contour plots to the right of the three-space perspectives.

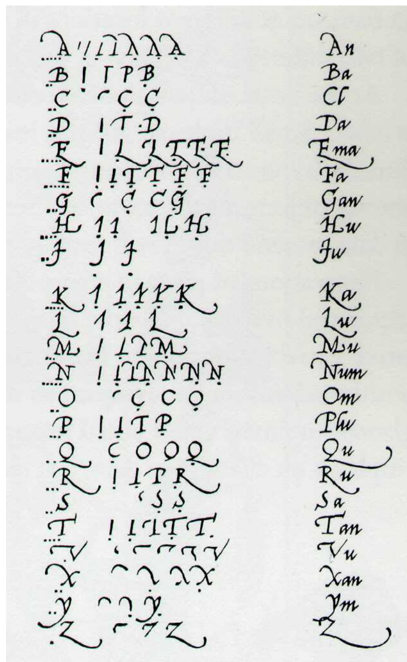




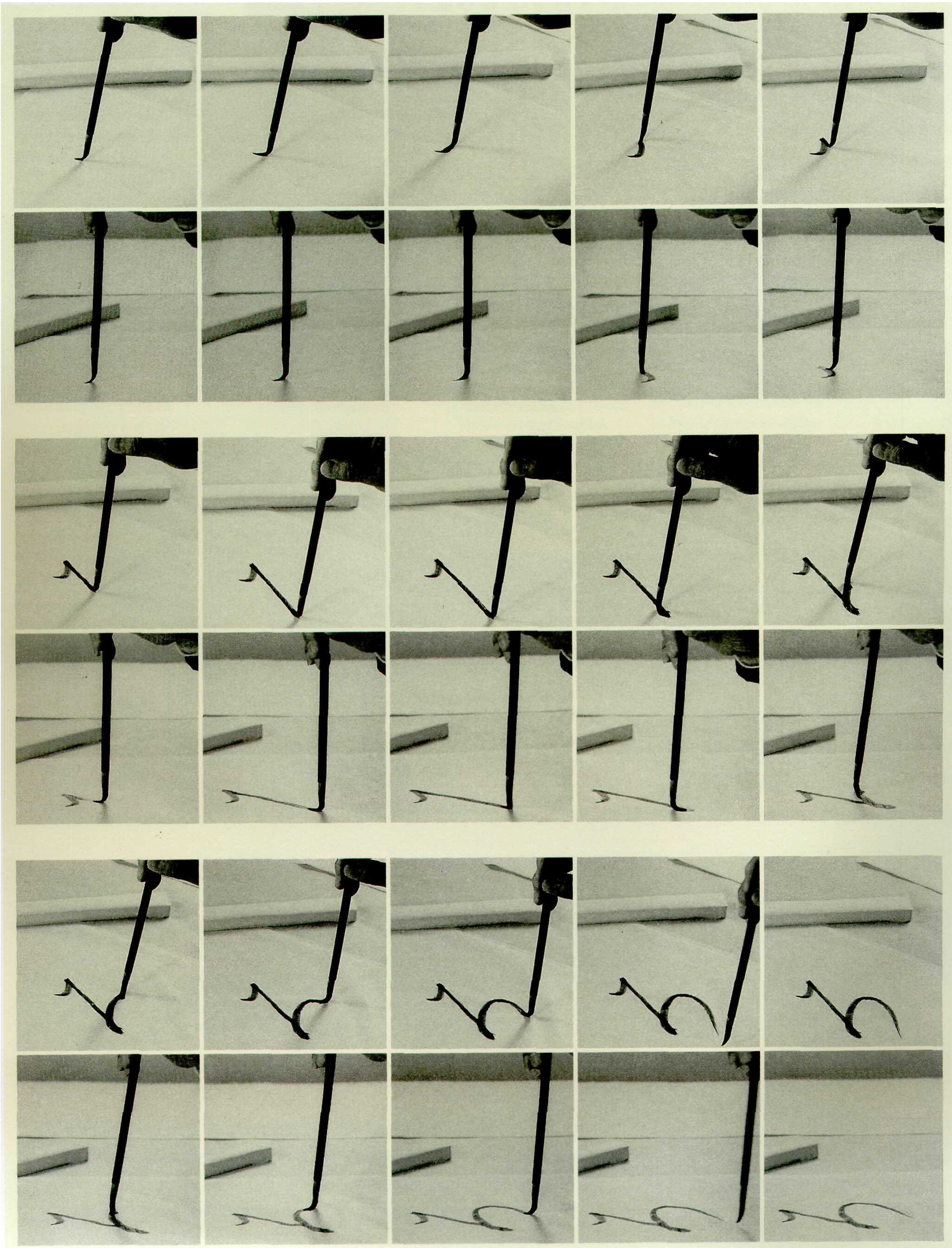
Rules and Regulations for the Government of Employees of the Operating Department of the Hudson & Manhattan Railroad Company, Effective October 1st, 1g23 (New York, 1923), p. 21. Redrawn.

SMALL multiples reveal, all at once, a scope of alternatives, a range of options. Above, varying signal lights on the ends of a train are entabled in a rulebook for railroad employees. Our redrawing mutes the repeated train outline and brings forward differentiating colors.

At far right, these photographs capture pressure, direction, and speed of the calligraphic brush as it draws a single Kana character. Images are indexed by time (→) and by dual camera angle (↑). The paired series of photographs link hand, brush, and character (top row). The second row shows pressure and bend of the brush-tip - and the consequent width of line. The sequence has a magical quality, reflecting a remark of Garry Winogrand, the photographer: "There is nothing as mysterious as a fact clearly described."



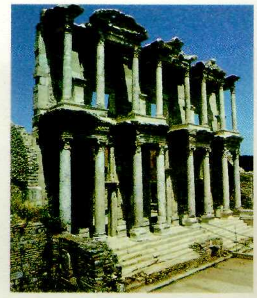
At right, Kayu Hirata, *Tsugi Shiki Shi*, volume 25 *of Shodo Giho Koza [Techniques in Calligraphy]* (Tokyo, 1974), p. 30. Above, without the aid of film, Mercator shows a similar sequence, the proper ordering of strokes in the formation of capital letters. Gerardus Mercator, *Literarum Latinarum, quas Italicas cursoriasque vocant, scribendarum ratio* [*The method of writing the Latin letters, which are called italic and cursive*] (Louvain, 1540), chapter 6.



MURAL WITH BLUE BRUSHSTROKE

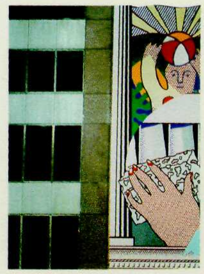
To make *Mural with Blue Brushstroke*, Lichtenstein drew on sources ranging from the most exalted to the most banal. Classical architecture (2, 14) provided inspiration, as did the site itself (8, where painted windows align with real ones). Homages to twentieth-century masters abound: Léger's people (1), Kelly's color fields (6), Matisse's split philodendron form (9), Arp's silhouettes (10, echoed in a piece of Swiss cheese), De Kooning's brushstrokes (12), Stella's triangles and French curves (15), Johns's flagstones (16), and Braque's balusters (20). Art styles—like Abstract Expressionism (11, 12, and 13, the latter with its "perfect painting"), Cubism (20), and Art Deco (21)—and artist's tools (4, 5, and 15) appear. And bustling around amid all this high culture are images of everyday modern life, those perennial sources of fascination to Lichtenstein: sunbursts (3), copy books (17), advertisements (7), food and drink (10, 18), and, of course, comic strips (19).

1. Detail of *The Dance* by Fernand Léger



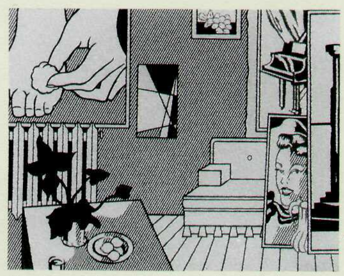
2. Facade, Library of Celsus, Ephesus

7. Ad for Elgin watches, 1950s

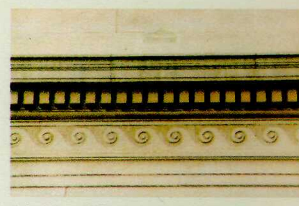


8. Detail of the mural in place at Equitable

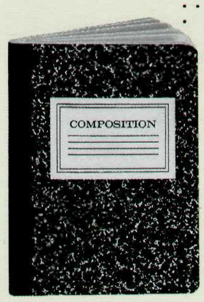
9. Henri Matisse, *Music*, 1939



13. Roy Lichtenstein, *Artist's Studio —Foot Medication*, 1974

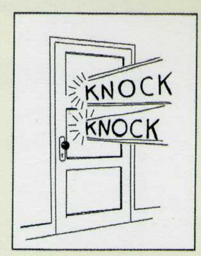


14. Entablature on downtown New York building



17. Classic black-and-white composition book

18. Roy Lichtenstein, *Still Life with Red Wine*, 1972

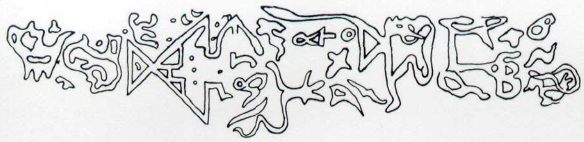


19. Roy Lichtenstein, *Knock Knock*, 1961

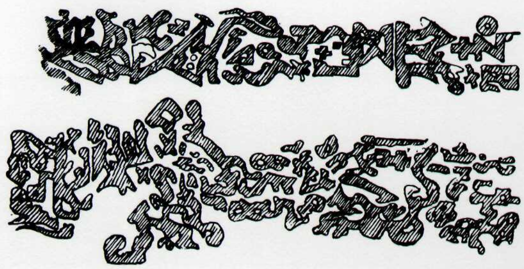
Roy Lichtenstein created "Mural with Blue Brushstroke" for the lobby of a building in New York. The large painting contains allusions to other works by Lichtenstein as well as many quotations (some a bit vaporous) from other artists. For a book describing the mural, Samuel

Antupit (who was also responsible for the annotated invoice from the hospital) crafted this superb double-page spread, linking 21 small images from various sources to the mural at center. This design both isolates detail and places it in context.

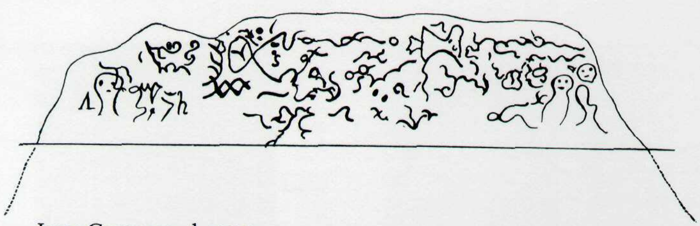
Roy Lichtenstein: Mural with Blue Brushstroke, essay by Calvin Tomkins, photographs and interview by Bob Adelman (New York, 1988), pp. 30-31.



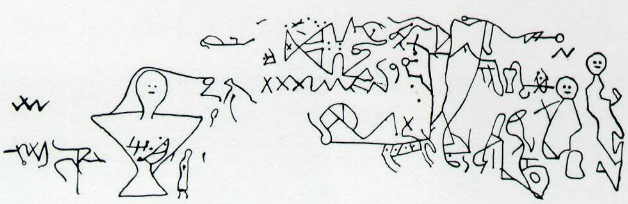
Danforth, 1680



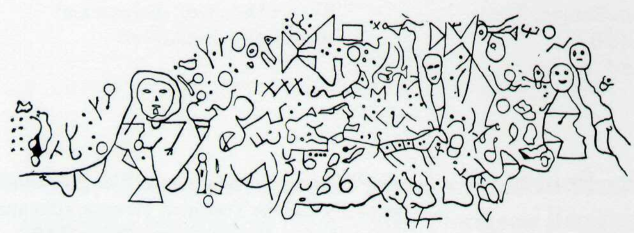
Cotton Mather, 1712



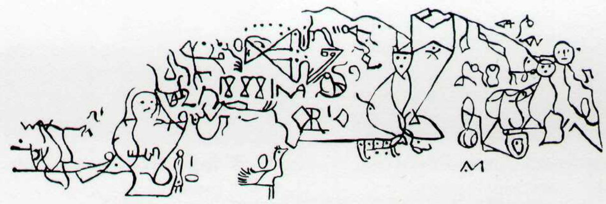
Isaac Greenwood, 1730



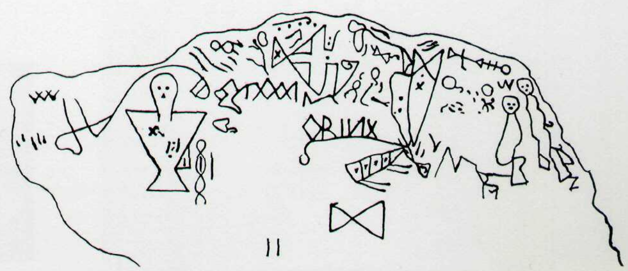
Stephen Sewell, 1768



James Winthrop, 1788

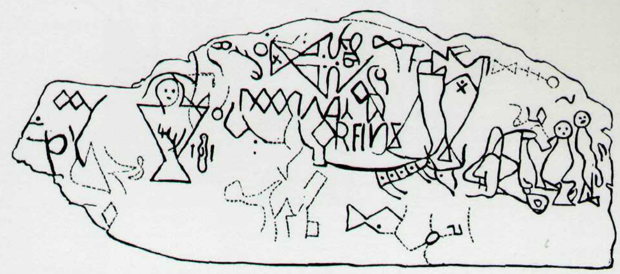


Baylies and Goodwin, 1790

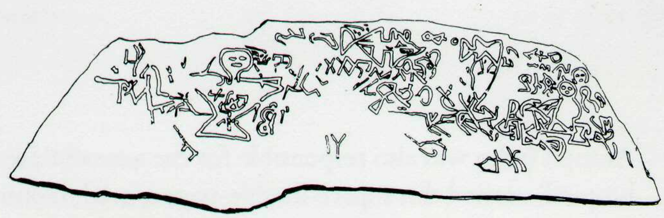


E. A. Kendall, 1807

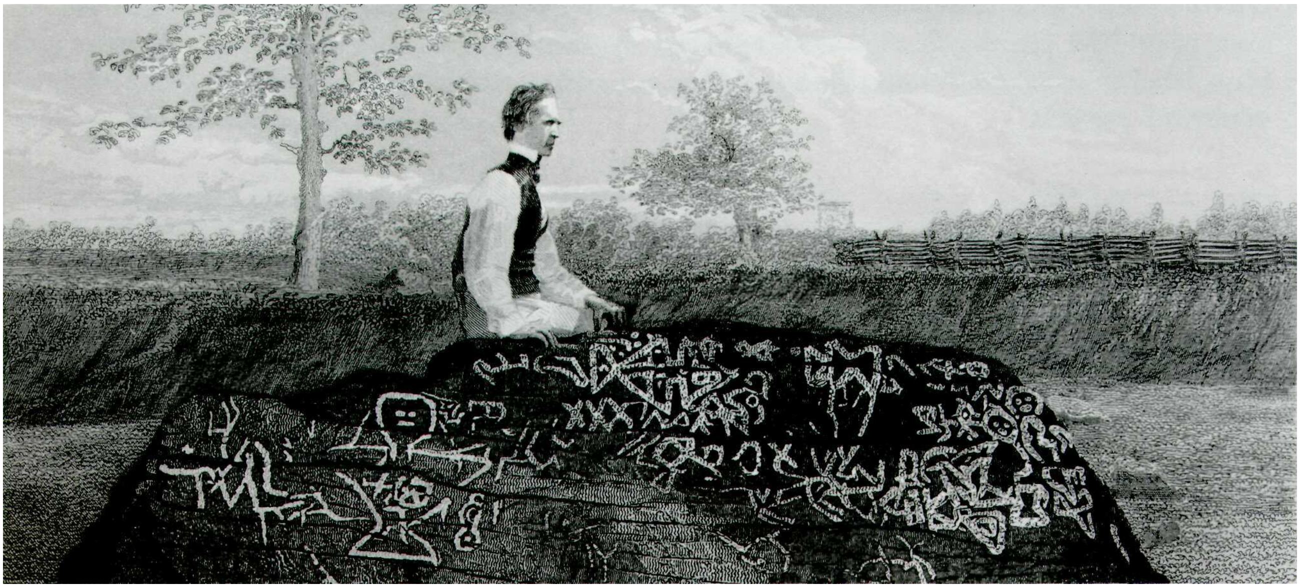
Job Gardner, 1812



Rhode Island Historical Society, 1830



Henry R. Schoolcraft, 1854



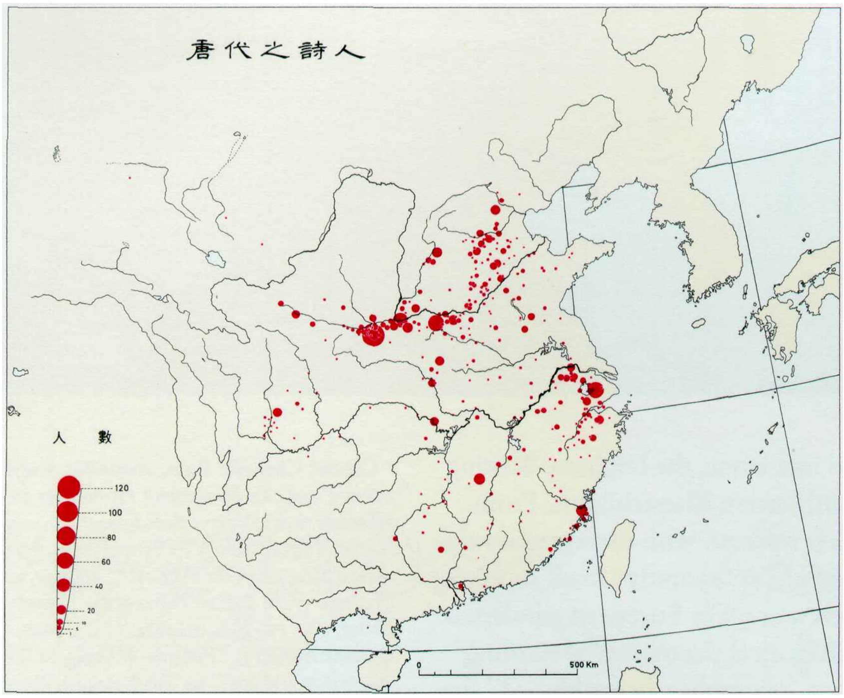
WITH figures and pictographs chipped into stone, the Dighton Writing Rock sits near the Taunton River in southeastern Massachusetts. From 1680 onwards, observers sketched the inscriptions, with divergent results. Same rock, different views, arrayed here in a comparative small multiple. Some of these uncertain drawings, when sent off to European scholars, were then converted into far-reaching historical discoveries of startling visits to the New World. One researcher "triumphantly established" the marks as Scythian; a distinguished Orientalist detected the word *melek* (king) on the rock; others thought they saw Phoenician or Runic script. A Scandinavian antiquary translated the drawings into an account of a pre-Columbian sojourn to America by a party of Thorfinn the Hopeful. Since the writing resembles that on the Indian God Rock hundreds of miles southwest, such logic places the Vikings far inland, deep into what is now West Virginia and Ohio. All this scholarship of wishful thinking denies priority to the original Native-American residents; local experts conclude that the marks are Algonquin.[1]

A focused small multiple, below, shows the history of variations in the ghost-like figure, enforcing comparisons over time (the ghosts even could be spaced in proportion to the date they were drawn):

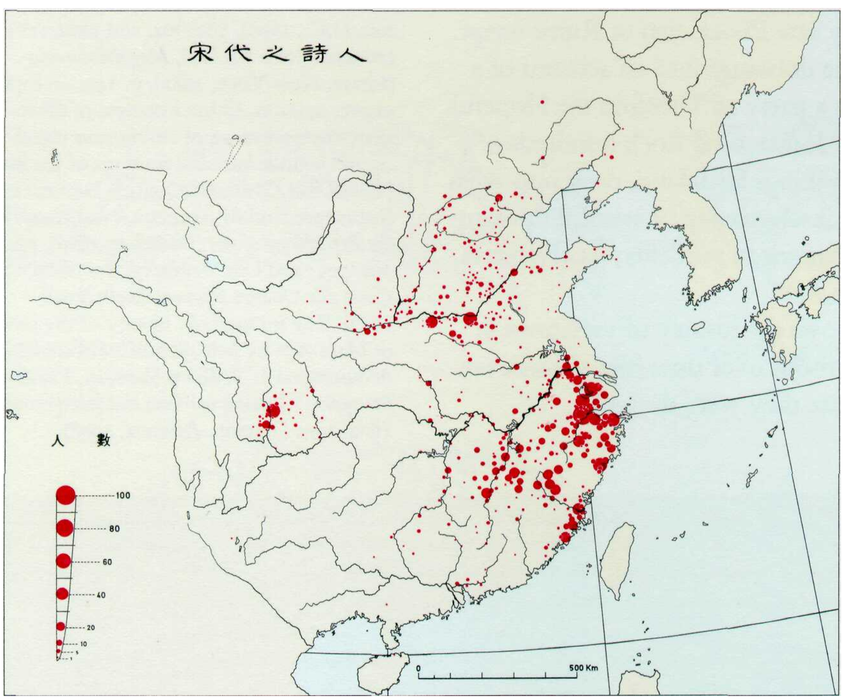
[1] Charles Christian Rafn, *Antiquités Américaines d'après les Monuments Historiques des Islandais et des Anciens Scandinaves* (Copenhagen, 1845); Henry R. Schoolcraft, *Information Respecting the History, Condition, and Prospects of the Indian Tribes of the United States*, Part IV (Philadelphia, 1854), plate 14. Garrick Mallery, "Picture-Writing of the American Indians," in *Tenth Annual Report of the Bureau of Ethnology of the Secretary of the Smithsonian Institution, 1888-89* (Washington, D.C., 1893), 762-764, and plate LIV; redrawn. John Michell, *Megalithomania* (Ithaca, New York, 1982), p. 145, on local expert opinion. Other instances of divergent interprétations of ambiguous visual signais include variable readings of the floor plan of San Carlo alle Quattro Fontane in Rome; see Rudolf Arnheim, *New Essays on the Psychology of Art* (Berkeley, 1986), pp. 301-309; and Leo Steinberg, *Borromini's San Carlo alle Quattro Fontane* (New York, 1977). The melancholy history of the canals of Mars seen by Schiaparelli and Lowell is documented in William Sheehan, *Planets and Perception: Telescopic Views and Interpretations, 1609-1901)* (Tucson, Arizona, 1988).

DURING the last 1,260 years in China, where did poets flourish? How many poets? And have their birthplaces changed over the years? Four maps, based on an inherently imperfect historical record, address these prominent questions.

Redrawn from Chen Cheng-Siang, *An Historical and Cultural Atlas of China* (Tokyo, 1981), maps 36, 50, 62, and 82.



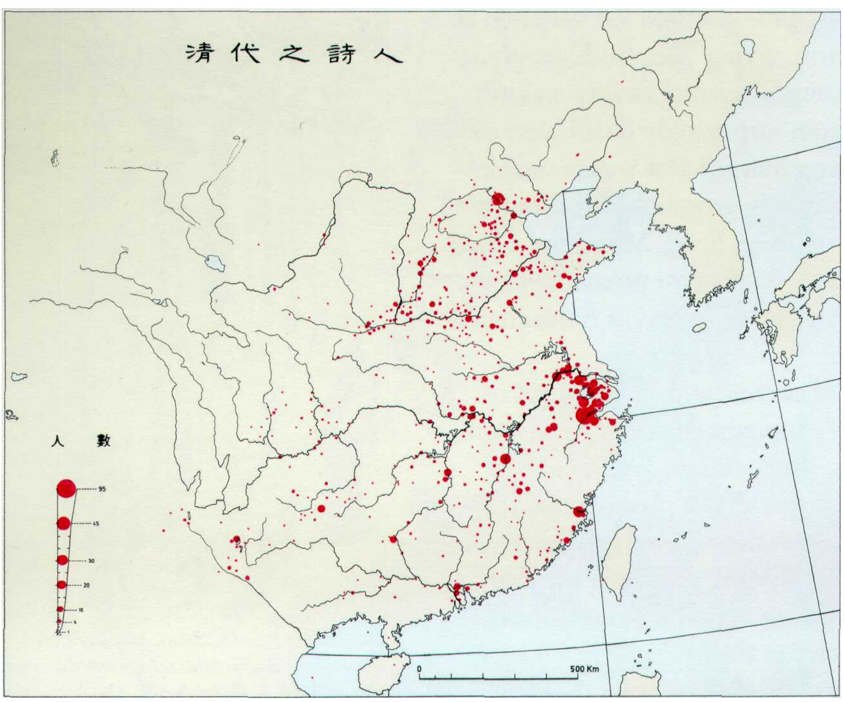
Birthplaces of the 2,625 Tang poets, 618-907



Birthplaces of the 2,377 Sung poets, 969-1279

Shown is the geographic distribution of poets (grand total 10,086) during four dynasties, with their birthplaces shifting through centuries toward southeast China and concentrating—as is the case for so much human activity—in a relatively few areas.

Birthplaces of the 3,005 Ming poets, 1368-1644



Birthplaces of the 2,079 Ching poets, 1644-1911

Redrawn from Chen Cheng-Siang, *An Historical and Cultural Atlas of China* (Tokyo, 1981), map 91.

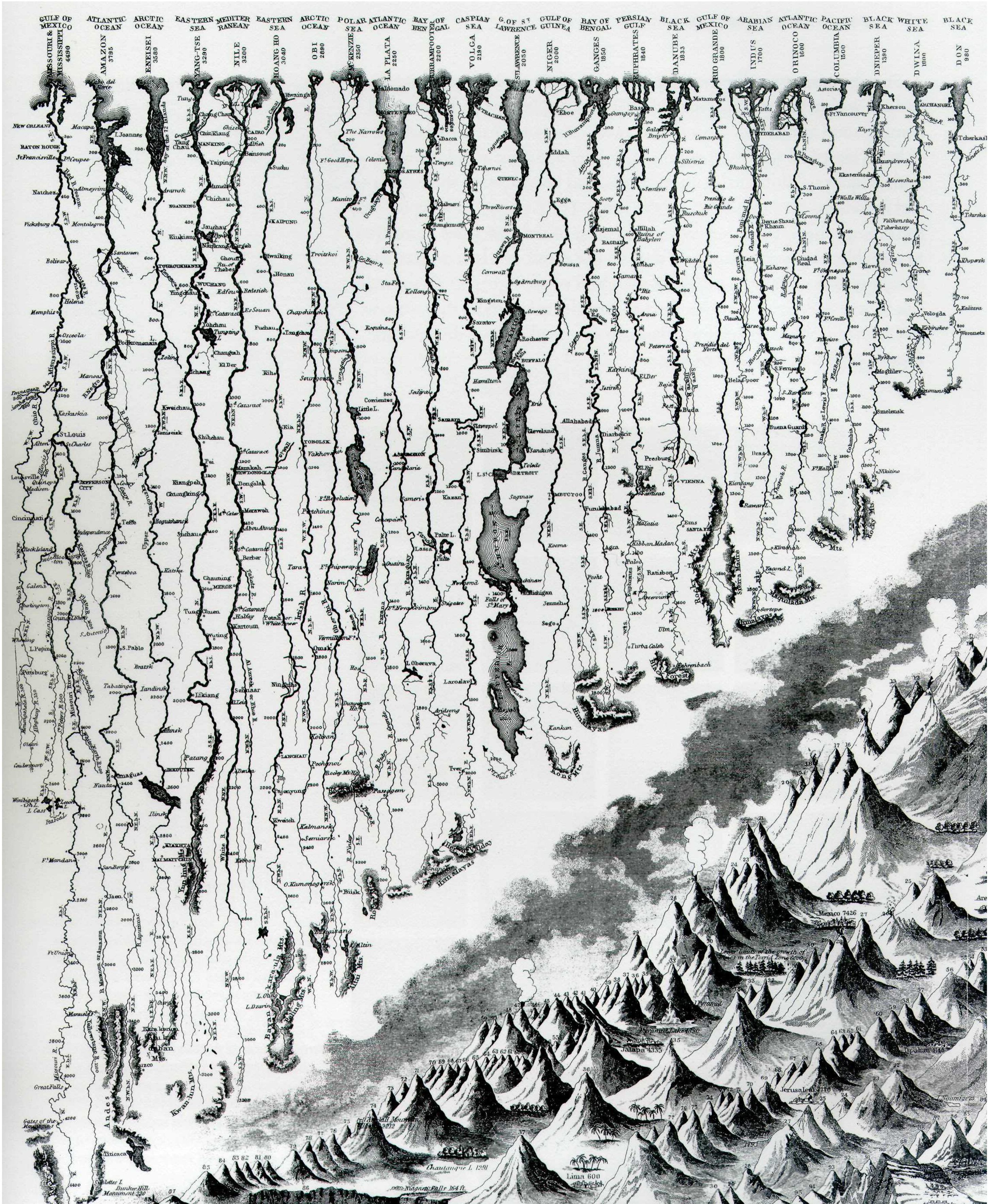
Ta-ch'eng Ch'eng, *Ma-tsu chuan* (Taipei, 1955), illustration 29.

And, finally, a map of distribution of temples of Matsu (T'ien Hou), the most famous sea goddess of China. With a sterling reputation for miracles, she receives prayers of fishermen and sailors during stormy weather; and when the sea is as dark as ink, she provides a torch on the top of the mast to guide small boats to safety. In recent times, the story goes, one mother (an alleged descendant of the goddess) left her child at a temple while going to work on the farm, saying "Sea Goddess, please take heed." Matsu's reaction to supervising a day-care facility was not recorded. Our display here, growing from surpassingly incomplete data, marks prefectures with a temple honoring Matsu.[2] But we are unable to make the long-awaited comparisons among geographic distributions of sea-goddess temples and birthplaces of Tang, Sung, Ming, and Ching poets—because the poets are stranded over on the two preceding pages. *Comparisons must be enforced within the scope of the eyespan,* a fundamental point occasionally forgotten in practice.

The struggle between maintenance of context and enforcement of comparison is reflected in a 19th-century topographic diagram at right. Surveying lengths of the world's rivers, the chart hangs them out, in parallel more or less, while still retaining specifics of place-names, lakes, and river branches. Note the various sequences of lakes, here linearly arranged. Without such detail, this is just another decorated bar chart. Some ardent typography sets oceans rippling at top. The juxtaposed mountains are less successful, too arbitrary in their relocation, and too stylized and lacking the nice local particulars of the rivers.

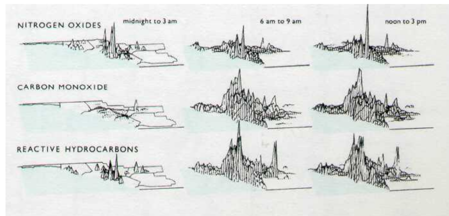
[2] A recent account is by James L. Watson, "Standardizing the Gods: The Promotion of T'ien Hou ('Empress of Heaven') Along the South China Coast, 960-1960," in David Johnson, Andrew J. Nathan, and Evelyn S. Rawski, eds., *Popular Culture in Late Imperial China* (Berkeley, 1985), 292-324.

Joseph Hutchins Colton, *Johnson's New Illustrated Family Atlas with Physical Geography* . . . (New York, 1864), pp. 10-11.



GULF OF MEXICO
MISSOURI & MISSISSIPPI 4490
ATLANTIC OCEAN
AMAZON 3795
ARCTIC OCEAN
ENEISEI 3580
EASTERN SEA
YANG-TSE 3290
MEDITERRANEAN
NILE 3200
EASTERN SEA
HOANG HO 3040
ARCTIC OCEAN
OBI 2890
POLAR SEA
McKENZIE 2350
ATLANTIC OCEAN
LA PLATA 2250
BAY OF BENGAL
BRAHMAPOOTER 2200
CASPIAN SEA
VOLGA 2190
G. OF ST LAWRENCE
St LAWRENCE 2050
GULF OF GUINEA
NIGER 2000
BAY OF BENGAL
GANGES 1850
PERSIAN GULF
EUPHRATES 1840
BLACK SEA
DANUBE 1833
GULF OF MEXICO
RIO GRANDE 1800
ARABIAN SEA
INDUS 1700
ATLANTIC OCEAN
ORINOCO 1600
PACIFIC OCEAN
COLUMBIA 1500
BLACK SEA
DNIEPER 1390
WHITE SEA
DWINA 1090
BLACK SEA
DON 980
NORTH AMERICA
SOUTH AMERICA
ASIA
AFRICA
EUROPE

Simultaneous two-dimensional indexing of the multiplied image, flatland within flatland, significantly deepens displays, with little added complication in reading. These neurometric maps record distributions of brain electrical activity, arraying data over a matrix of color images — with frequency bands (delta, theta, alpha, and beta) sorting the columns, and individual diagnosis forming the rows. The contour lines depict only the average differences (normalized z-scores) of the *row group* compared to a healthy reference *group*, and thus do not show overlaps or extreme outlying values of all the *individual* members of each group.[3] Graphically, this recursive design resembles the Los Angeles smog chart that we saw in Chapter 1, where maps were themselves spread on two dimensions, type of pollution and time of day.



Normal
(n = 60)

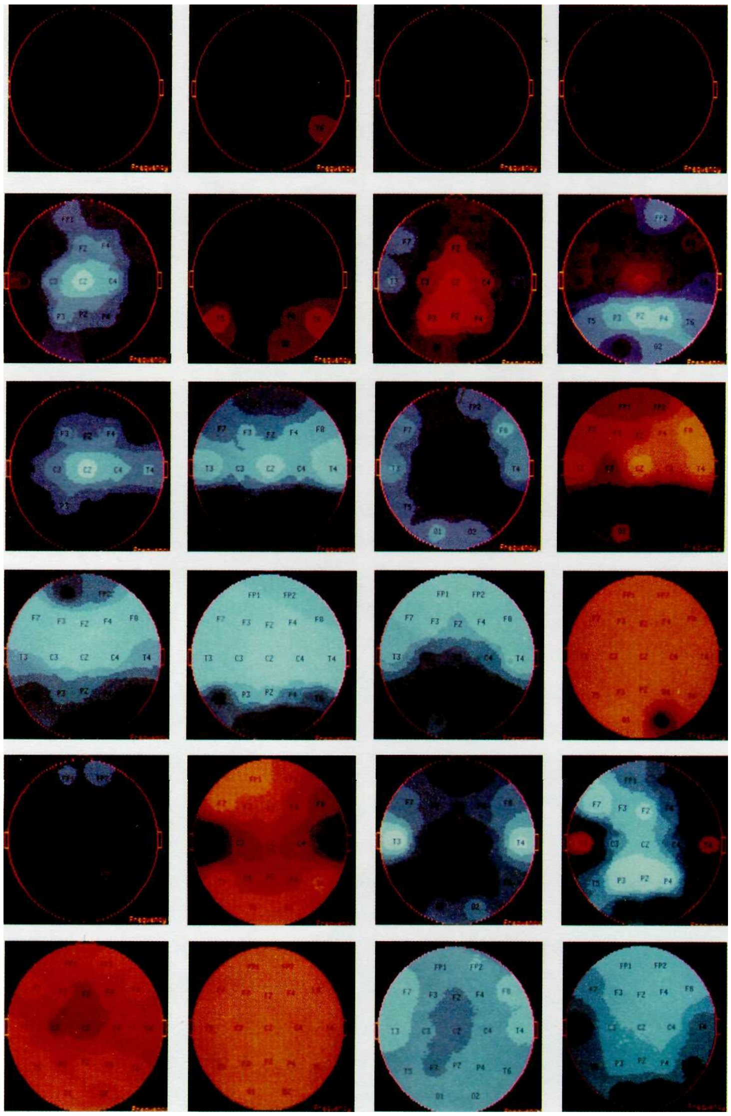
Unipolar
depression
(n = 69)

Bipolar
depression
(n = 35)

Alcoholism
(n = 30)

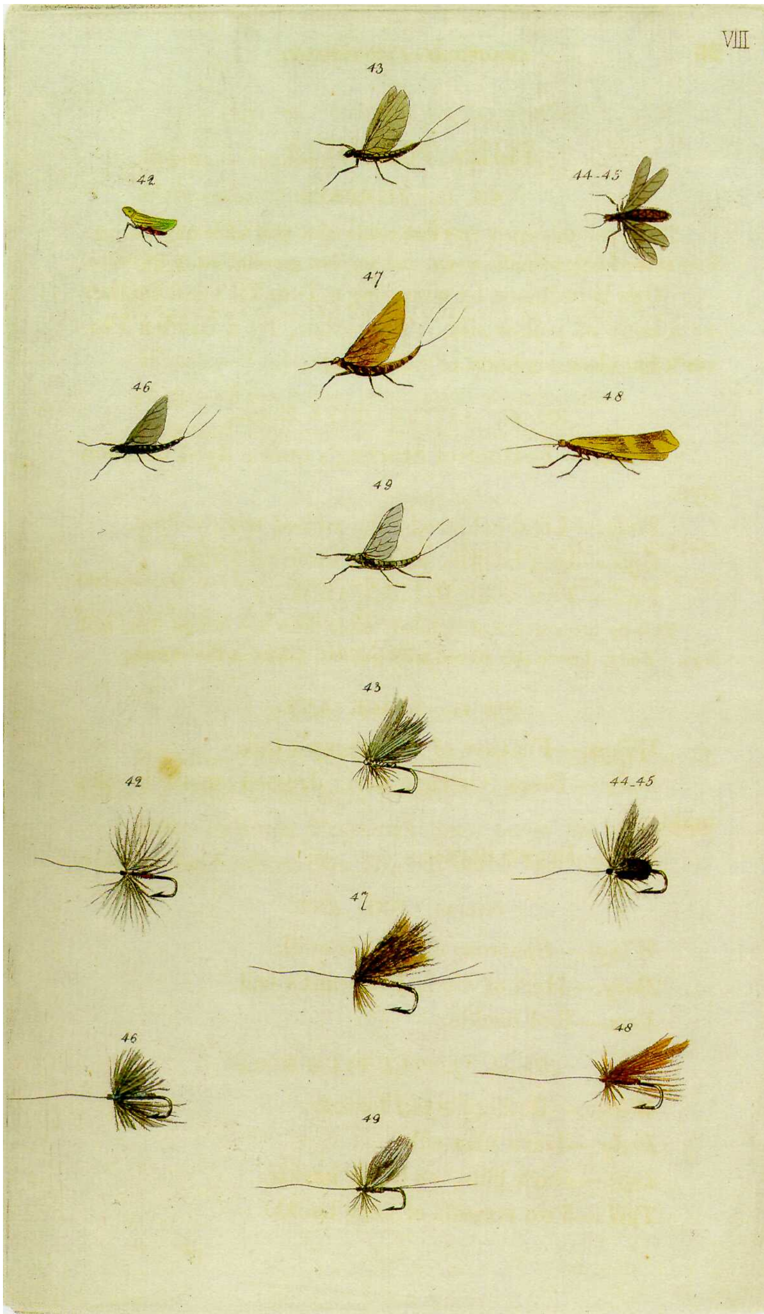
Schizophrenia
(n = 20)

Dementia
(n = 93)



Z% delta | Z% theta | Z% alpha | Z% beta

[3] E. R. John, L. S. Prichep, J. Fridman, and P. Easton, "Neurometrics: Computer-Assisted Differential Diagnosis of Brain Dysfunctions," *Science*, 239 (January 8, 1988), 162-169. The authors conclude: "Healthy persons display only chance deviations beyond the predicted ranges. . . . Patients with neurological impairments, subtle cognitive dysfunctions, or psychiatric disorders show a high incidence of abnormal values. The magnitude of the deviations increases with clinical severity. Different disorders are characterized by distinctive profiles of abnormal brain electrical features. . . . These methods may provide independent criteria for diagnostic validity, evaluations of treatment efficacy, and more individualized therapy."



John Jackson, *The Practical Fly-Fisher; More Particularly for Grayling or Umber* (London, 1854), plate VIII, at 26-27, insects and flies for July and August.

In our neurometric example at left, the dark colors surrounding each image generate disruptive white stripes. Locations can be signaled by nearly silent methods, as above, where an implicit grid pairs each insect with its fly-fishing simulation. And the limited but focused color here is more effective than strong rainbow colors, for reasons now to be revealed.