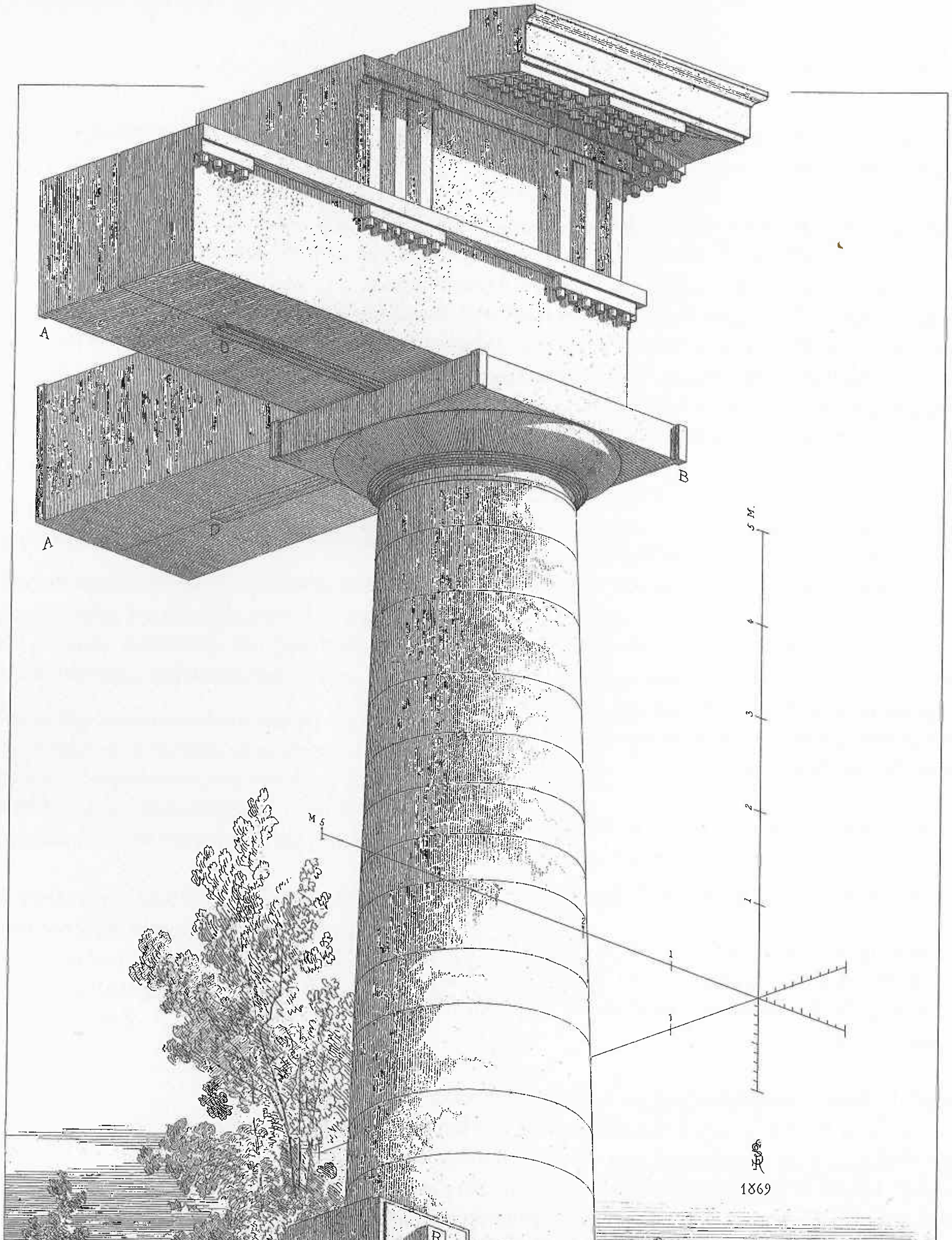
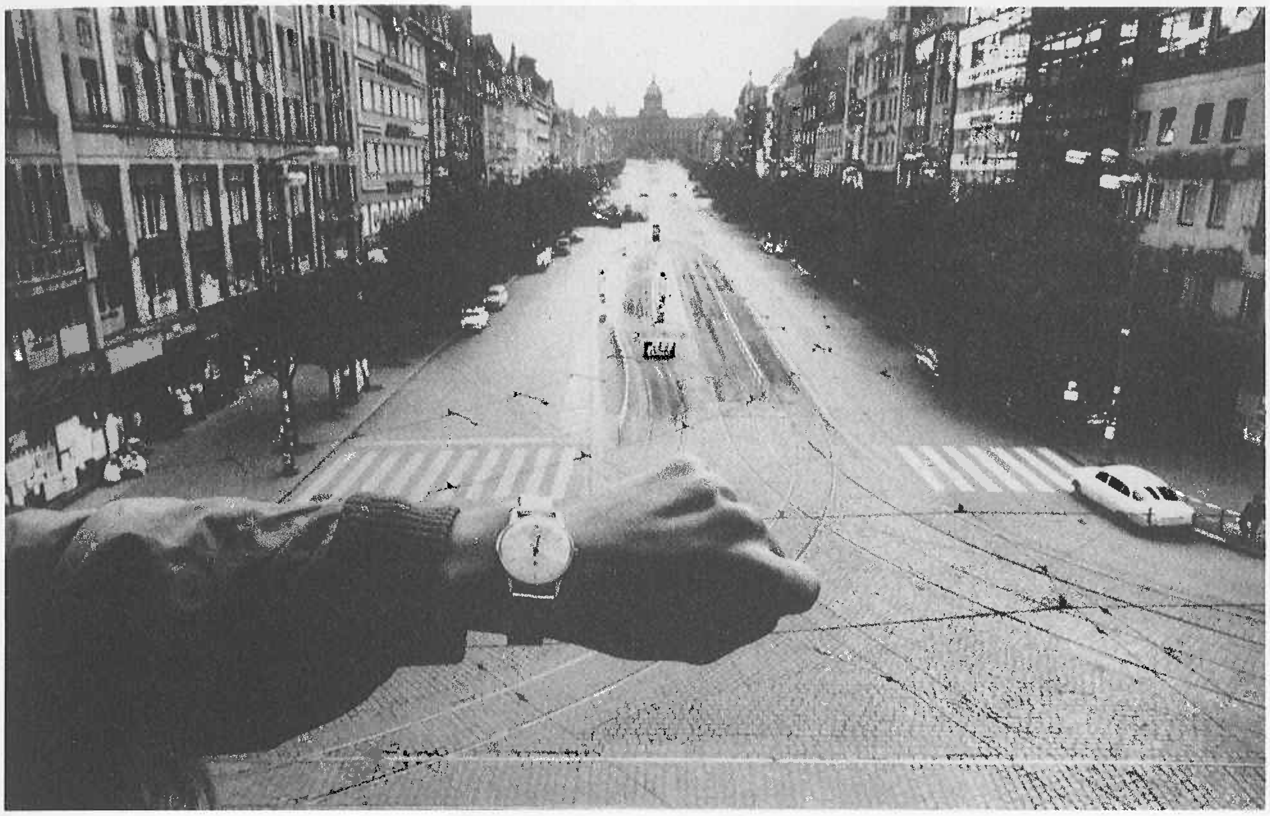


DESSINE PAR A CHOISY

GRAVE PAR H·SAUVESTRE

1 *Images and Quantities*

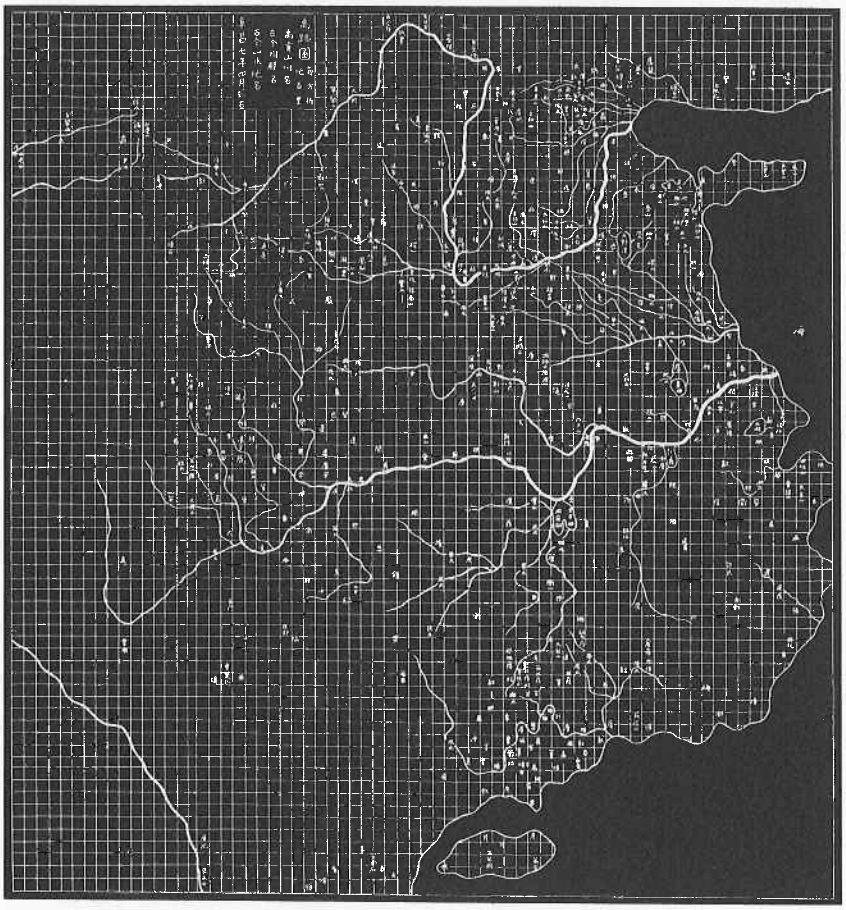


Josef Koudelka, *The Urge to See*, Prague, August 22, 1968.

Our thinking is filled with assessments of quantity, an approximate or exact sense of number, amount, size, scale. In scientific work, both order-of-magnitude reasoning and precise measurements are pervasive. How are such quantities represented in visual expressions of ideas, experience, evidence? How are moving images, photographs, diagrams, maps, and charts to be scaled and labeled? And what makes images quantitatively eloquent?

Visual techniques for depicting quantities include *direct labels* (for example, the numerically labeled grids of statistical graphics, or, at left, dimensional tripods in architectural drawings); *encodings* (color scales); and *self-representing scales* (objects of known size appearing in an image). Using all these methods, Josef Koudelka's haunting and vehement photograph, *The Urge to See*, testifies to the empty streets during the 1968 Soviet invasion of Czechoslovakia that ended the Prague Spring of democratic reform. In the foreground, a watch documents the hour (*direct label*), as the shadows and gray light hint at the time of day (*encoding*), while in the distance Soviet tanks surround the national museum (*self-representing scales*, as many familiar objects in perspective demarcate the street and the photographer's location).

Auguste Choisy, *L'art de bâtir chez les romains* (Paris, 1873), plate XXIII, Segeste.



The original stone engraving is 32 by 31 in or 80 by 79 cm; redrawn from Edouard Chavannes, "Les Deux Plus Anciens Spécimens de la Cartographie Chinoise," *Bulletin de l'École Française de l'Extrême Orient*, 3 (1903), pp. 214–247, Carte B.

Maps express quantities visually by location (two-dimensional addresses of latitude and longitude) and by areal extent (surface coverage). Some 900 years ago a fully scaled map was engraved in stone by precocious Chinese cartographers. The *Yu ji tu* or the Map of the Tracks of Yu is

> . . . the most remarkable cartographic work of its age in any culture, carved in stone in +1137 but probably dating from before +1100. . . . The coastal outline is relatively firm and the precision of the network of river systems extraordinary. . . . Anyone who compares this map with the contemporary productions of European religious cosmography cannot but be amazed at the extent to which Chinese geography was at that time ahead of the West. . . . There was nothing like it in Europe till the Escorial MS. map of about +1550.[1]

A note on the stone indicates that each grid square represents 100 *li*, a scale of map to world of approximately 1 to 4,500,000.

Despite their quantifying scales and grids, maps resemble miniature pictorial representations of the physical world. To depict relations between *any* measured quantities, however, requires replacing the map's natural spatial scales with abstract scales of measurement not based on geographic analogy. To go from maps of existing scenery to graphs of newly measured and collated data was an enormous conceptual step. Embodied in the very first maps were all the ideas necessary for making

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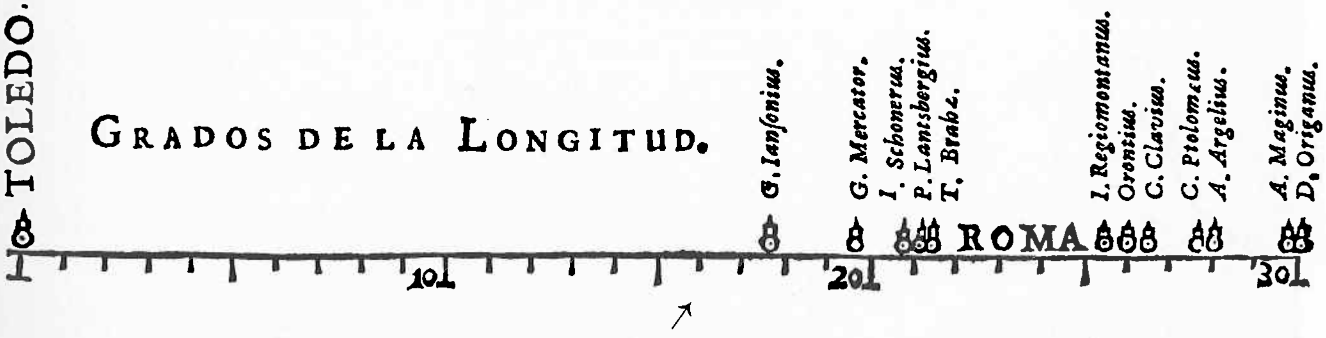
[1] Joseph Needham, *Science and Civilization in China, volume 3: Mathematics and the Sciences of the Heavens and the Earth* (Cambridge, 1959), pp. 547–549. See also Cao Wanru, *et al.*, eds., *Zhongguo gudai ditu ji* [*Atlas of Ancient Chinese Maps*] (Beijing, 1990); and Cordell D. K. Yee, "Reinterpreting Traditional Chinese Geographical Maps," in J. B. Harley and David Woodward, eds., *The History of Cartography, volume 2, book 2: Cartography in the Traditional East and Southeast Asian Societies* (Chicago, 1994), pp. 47–50.

statistical graphics—quantified measures of locations of nouns in two-dimensional space—and yet it took 5,000 years to change the name of the coordinates from *west-east* and *north-south* to empirically measured variables X and Y. The even longer history of art took a similar course: the naturalistic coordinate system of painted cave-wall and canvas was first dislocated by Cubism's fractured images from multiple viewpoints and then eventually abandoned altogether in 20th-century abstract painting, as the two dimensions of the canvas no longer referred to worldly scenery but only to themselves.

One of the earliest visual representations of statistical data was drawn in 1644 by Michael Florent van Langren, a Flemish astronomer to the Spanish court. Appropriately enough for statistics, this graph shows 12 diverse estimates of the distance between Toledo and Rome. Measured in degrees longitude, the scale locates Toledo, the historic Spanish city portrayed in El Greco's *View of Toledo*, at the prime meridian of 0°. All the longitudes are too large, perhaps a result of underestimating the earth's circumference. The correct distance is 16° 30′. Combining nouns with numbers, the chart cites the astronomers and cartographers making the estimates—Jansson, Mercator, Schoener, Lansberge, Brahe, Regiomontanus, Ptolemy, and others. On Langren's scale, the broadly inexact position of Rome, sprawled out 22° to 25° from Toledo, places it far east of its actual location and well across the Adriatic Sea into western Greece. A one-dimensional map of data, the chart is remarkably advanced for its time, spatially arranging (rather than merely recording in a table) various estimates of the same quantity. Furthermore, the data are distributed in relation to a putatively true value. Langren's chart appears to be the earliest display of a distribution of common measurements; and it is my candidate for the first statistical graphic ever.[2]



Michael Florent van Langren, *La Verdadera Longitud por Mar y Tierra* (Antwerp, 1644), p. 3. The purpose of the graph was to advance Langren's own method for the determination of longitude because of ". . . the existence of such enormous errors, as can be seen from the line, which shows the different distances that the greatest astronomers and geographers put between Rome and Toledo . . ."

By 1765, two-dimensional space was liberated from pictorially-based scales. J. H. Lambert described a *general* graphical grid (no more analogies to maps) for depicting systematic relations between measured quantities:

> We have in general two variable quantities, x, y, which will be collated with one another by observation, so that we can determine for each value of x, which may be considered as an abscissa, the corresponding ordinate y. Were the experiments or observations completely accurate, these ordinates would give a number of points

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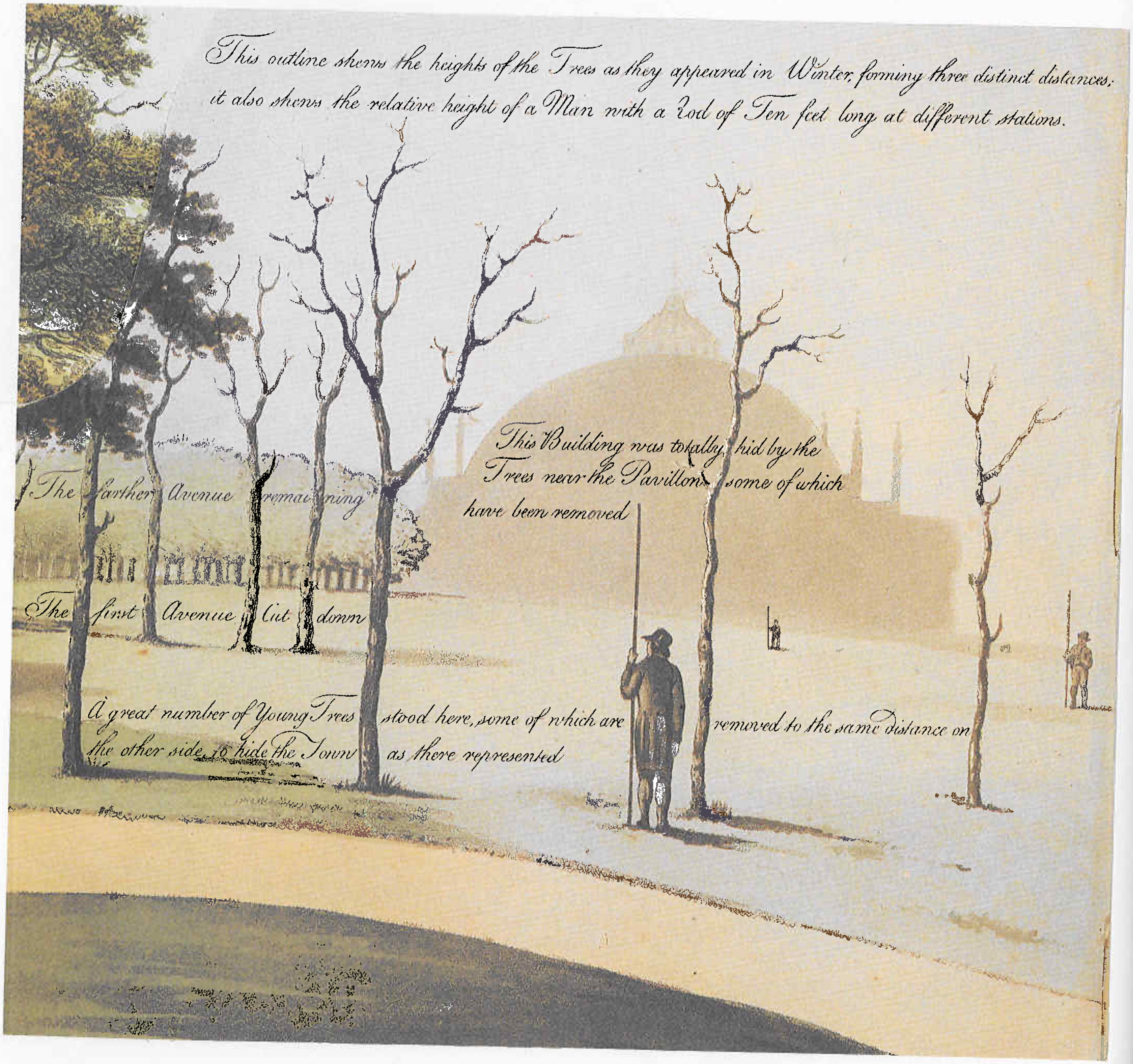
[2] On the history of statistical graphics, see H. Gray Funkhouser, "Historical Development of the Graphical Representation of Statistical Data," *Osiris*, 3 (November 1937), 269–404; and James R. Beniger and Dorothy L. Robyn, "Quantitative Graphics in Statistics: A Brief History," *American Statistician*, 32 (February 1978), pp. 1–11.

> through which a straight or curved line should be drawn. But as this is not so, the line deviates to a greater or lesser extent from the observational points. It must therefore be drawn in such a way that it comes as near as possible to its true position and goes, as it were, through the middle of the given points.[3]

Modern scientific graphics were now in place; the two-dimensional plane was quantified, available for any measured data. Used with fitted models, graphics could describe and characterize relations between variables—thus displaying the essential evidence necessary for establishing cause and effect.



Humphry Repton, *Designs for the Pavillon at Brighton* (London, 1808), pp. 40–41, detail, redrawn.

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[3] Johann Heinrich Lambert, *Beyträge zum Gebrauche der Mathematik und deren Anwendung* (Berlin, 1765), as quoted in Laura Tilling, "Early Experimental Graphs," *British Journal for the History of Science*, 8 (1975), pp. 204–205.

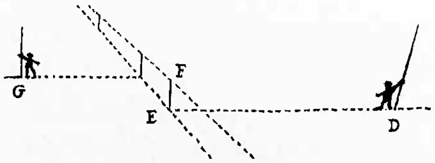
NOT a great many substantive problems, however, are exclusively two-dimensional. Indeed, the world is generally multivariate. For centuries, the profound, central issue in depicting information has been how to represent three or more dimensions of data on the two-dimensional display surfaces of walls, stone, canvas, paper, and, recently, computer screens. Of course, this is something that architects and painters (using perspective) and animators (using perspective and motion) have done for a long time.

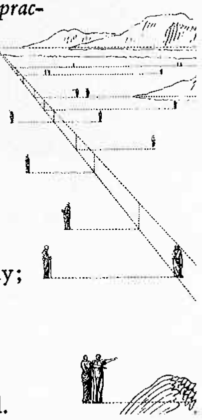
Humphry Repton, the British landscape architect, quantified the perspective drawing at left by placing three people with ten-foot poles around the grounds shown on the *before* flap. To explain the scaling, which combines the methods of self-representation and direct labels, words are integrated into the image: "This . . . shews the heights of the Trees as they appeared in Winter, forming three distinct distances; it also shews the relative height of a Man with a Rod of Ten feet long at different stations." These markers are necessary, since the perspective drawing itself reads ambiguously with regard to the sizes of objects in the background.[4] When the distances are reconstructed, however, it is clear that the pole-person in the deep background of the *before* flap is too small compared with the scaling of the *after* drawing.

Repton's shift in scaling dramatizes the visual consequences of his plans. In the *before* flap on top, the Brighton pavilion appears hidden, isolated, distant—impressions intensified by the tiny person and by the over-writing on the shadowy building. When the flap is raised to reveal the proposed redesign, the space between us and the pavilion has now become intimate and comfortable, filled with well-dressed visitors (giants, compared with the drab Lilliputian pole-people). A lush garden and patio dominate the foreground. Strolling in an area previously occupied by the miniature pole-person of *before*, an animated *after* couple walk a dog (which would be immense if seen in *before* space). Repton overreached in several other *before/after* comparisons, exaggerating the impact of his proposed improvements. In the plan at left, the designs of the flap, the pole-people, and the integrated text are all ingenious and delightful—but the integrity of the work is compromised by persistent visual cheating.

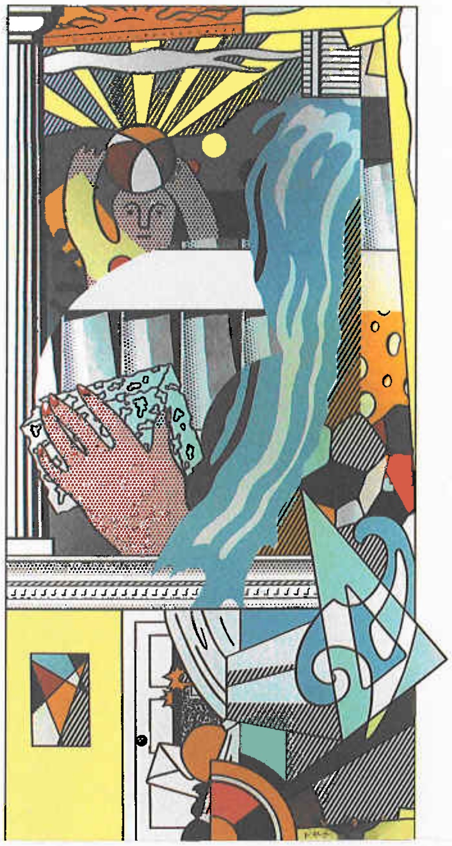
Sometimes images can be quantified in vivid and memorable ways, here in the photograph at right by a ladder-person. Lift the flap at lower right to reveal a self-representing scale for the vast *Mural with Blue Brushstroke* (68 by 32 ft, or 21 by 10 m). Roy Lichtenstein, the artist, stands atop the ladder!

Published photographs of works of art often fail to indicate a sense of the *sizes* of the original objects. Scholarly writings usually report the dimensions of the original; the scalings of published reproductions, however, vary capriciously in amount of reduction or enlargement. In practice, the sizes of reproduced images depend almost entirely on





[4] As early as 1642, pole-people were active in scaling recession for landscapes; above, Jean Dubreuil, *La perspective pratique nécessaire à tous peintres, graveurs, sculpteurs, architectes, orfevres, brodeurs, tapissiers et autres se servant du dessein* (Paris, 1642), plate 126, detail. A few years before Repton, Valenciennes deployed toga-people perspectively; at right, Pierre Henri de Valenciennes, *Élémens de perspective pratique à l'usage des artistes* (Paris, 1800), plate xxxv, detail.

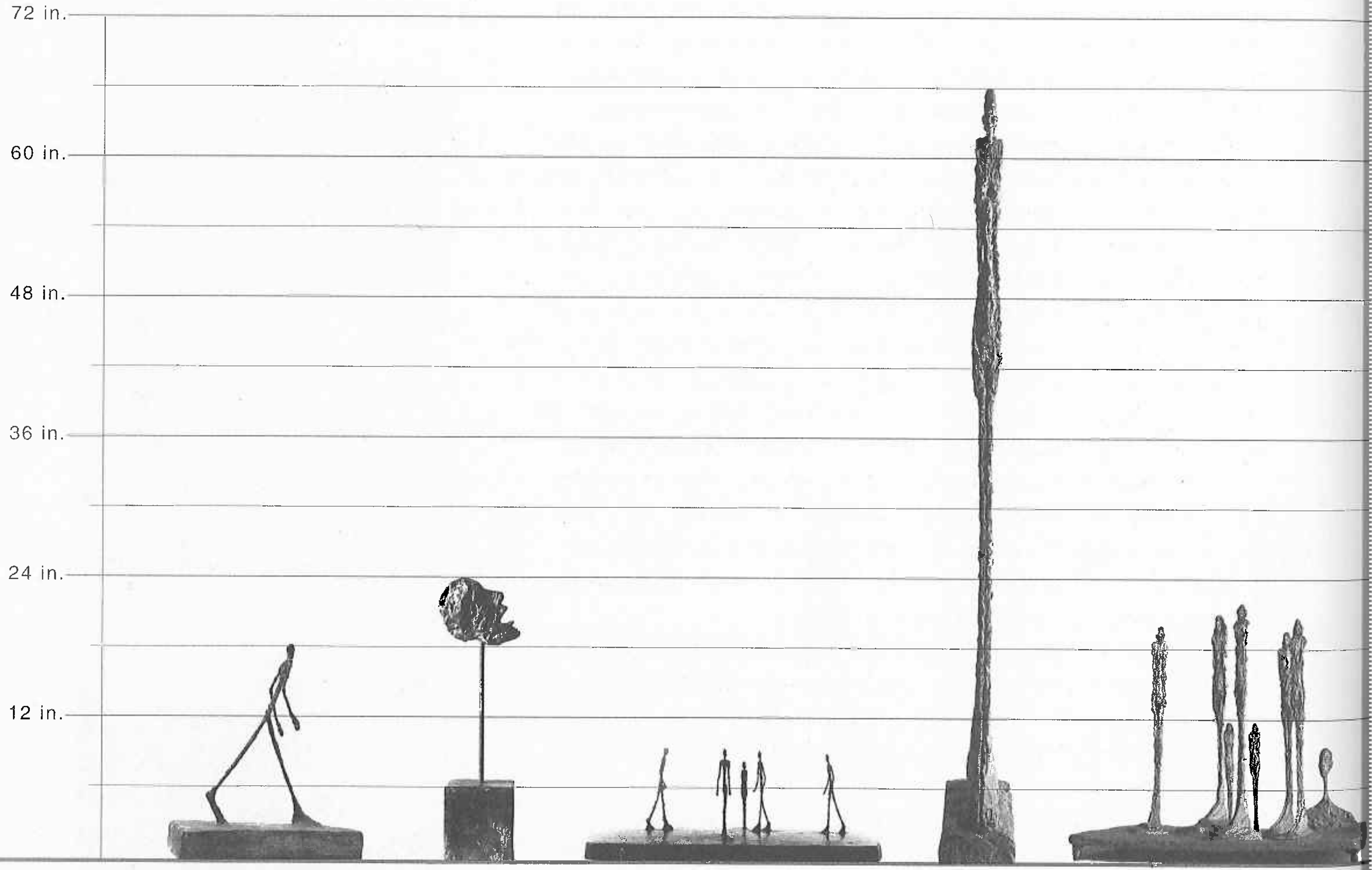


Photograph by Bob Adelman; originally published in *Roy Lichtenstein: Mural with Blue Brushstroke*, essay by Calvin Tomkins, with photographs and interview by Bob Adelman (New York, 1988), p. 127.

convenience of fit into the grid layout of a page or computer screen. Although the physical scope of a work of art is not always a relevant variable, for some works—Lichtenstein's mural, Monet's water lilies (paintings with areas of 250 square feet or 23 square meters), colossal statues of *David* or the People's Heroic Leader, posters, delicate and precious miniatures, postage stamps, typography—their size is surely an expressive factor.[5] How then can tiny, irregularly scaled reproductions tell us about measure, magnitude, presence, absolute or relative size?

Partial visual knowledge about size of a work can be conveyed by maintaining a consistent relative scale throughout an entire set of reproduced images, similar to a photograph showing a group of objects at a constant scale relative to one another, at least after adjusting for the effects of perspective. It is as if the objects to be reproduced were photographed all at once in a gallery: for example, the historic

Herbert Matter, *Thirteen Photographs: Alberto Giacometti and Sculptures* (Hamden, 1978). Redrawn. Norman Ives and Sewell Sillman, the publishers, printed only 56 copies of this exquisite portfolio.



1

Alberto Giacometti, 1965

2

Man Walking (Homme qui Marche).
1950
Bronze, 18¼" h.

3

Head of a Man on a Rod
(Tête sur Tige).
1947
Bronze, 24" h.

4

City Square (La Place).
1948
Bronze, 24¾" long.

5

Standing Woman
(Femme Debout).
1948
Bronze, 66" h.

6

Seven Figures and a Head (The Forest)
(7 Figures et 1 Tête (La Forêt)).
1950
Painted Bronze, 22" h.

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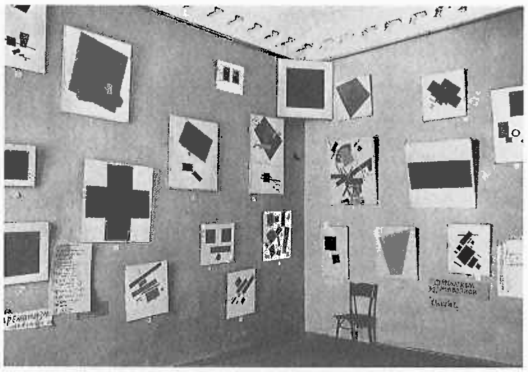
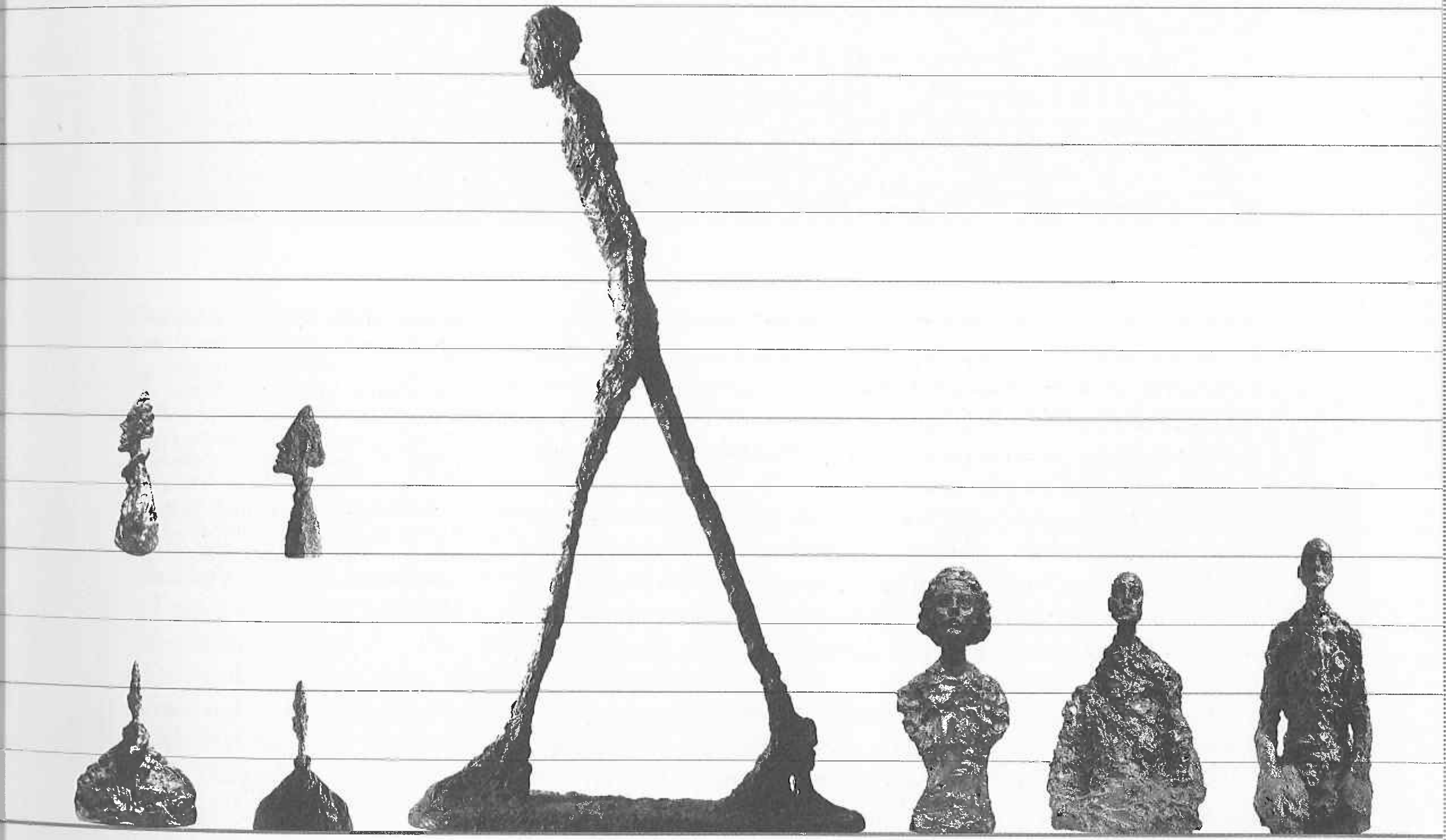
[5] On size and scale, see Meyer Schapiro, "On Some Problems in the Semiotics of Visual Art: Field and Vehicle in Image-Signs [1969]," in *Theory and Philosophy of Art: Style, Artist, and Society: Selected Papers* (New York, 1994), pp. 22–26.

photograph at right of Malevich's 1915 Petrograd "0–10" exhibition of Suprematist paintings, which are of course scaled relative to each other and to the known size of the chair in the corner.



A constant scale factor is used below in this visual table of contents for Herbert Matter's portfolio of photographs of Alberto Giacometti's sculptures. Each sculpture is measured and scaled on a common grid in an extraordinary gallery of images. (This design is also helpful for field guides to birds, fish, plants, and the like.) Titles, dates, and dimensions are shown, with front and side views for items 7, 8, 9. At far lower left, the blank first entry refers to a portrait of Giacometti, whose head is self-scaling and need not be placed on a grid. Designed by Herbert Matter, the original published sheet is large, 20 by 48 inches, or 51 by 123 cm. On that sheet, the sculptures are depicted at 19% of their actual size; here, they are all at 7% of actual size, small but comparable.



7

Diego in a jacket
(Diego au Blouson).
1953
Bronze, 14" h.

8 & 9

Bust of Diego
(Buste de Diego).
1954
Bronze, 13¼" h.

10

Walking Man I (Homme qui Marche I.).
1959-1960
Bronze, 72" h.

11

Bust of Annette VIII
(Buste d'Annette VIII).
1962
Bronze, 23¼" h.

12

Bust of Elie Lotar
(Buste d'Elie Lotar).
1965
Bronze, 22¾" h.

13

Elie Lotar
(Elie Lotar).
1965
Bronze, 25¾" h.

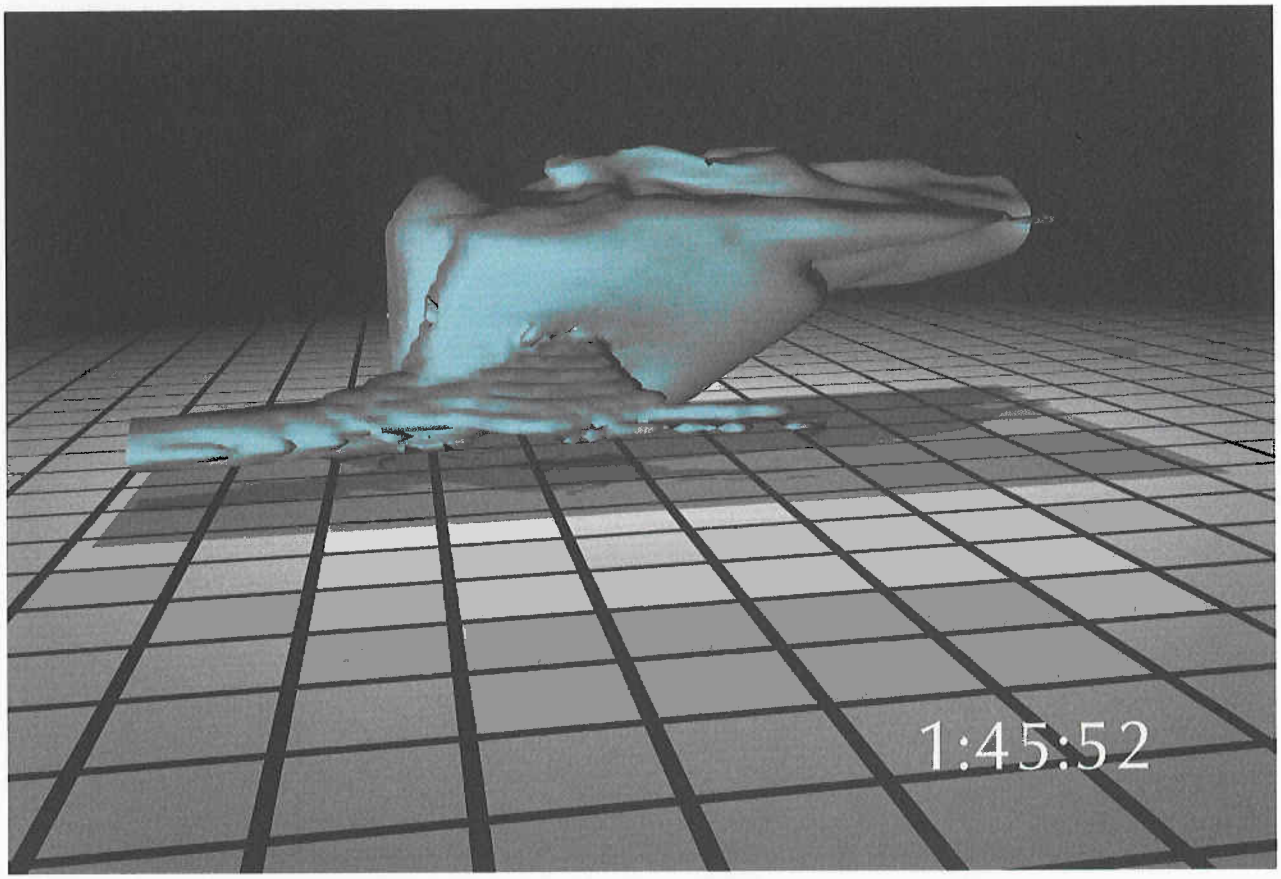
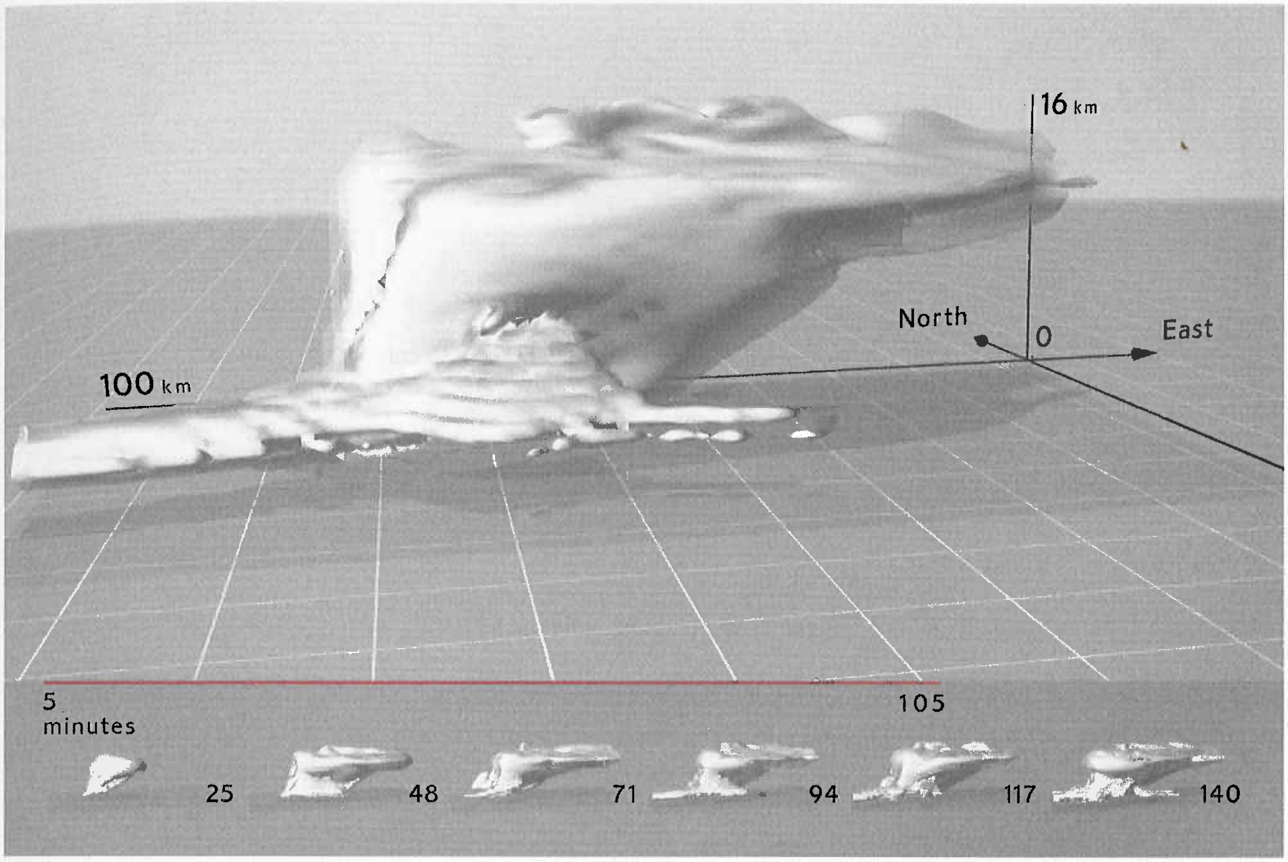


Image from the videotape "Study of a Numerically Modeled Severe Storm," National Center for Supercomputing Applications, University of Illinois at Urbana-Champaign, described in Robert B. Wilhelmson, Brian F. Jewett, Louis J. Wicker, Matthew Arrott, Colleen B. Bushell, Mark Bajuk, Jeffrey Thingvold, and Jeffery B. Yost, "A Study of the Evolution of a Numerically Modeled Severe Storm," *International Journal of Supercomputer Applications*, 4 (Summer 1990), pp. 20–36.

THE dequantification characteristic of art reproductions is also seen in scientific and technical imaging. Shown above is a video frame from a numerical model simulating a thunderstorm. Based on nine time-dependent partial differential equations as well as data gathered during a severe storm in Oklahoma and Texas, this supercomputer animation begins with a small cumulus cloud that grows into a fully developed storm. The five-minute movie describes a storm lasting two hours and twenty minutes, as indicated by the conspicuous time-stamp at lower right. Beneath the cloud, a rectangle delineates a two-dimensional projection of the computational domain. Near the ground, the cloud is trimmed away, revealing the grid and creating a sense of movement of the storm against the grid plane.

This is a classic of scientific visualization. Nevertheless, a redesign can improve the animation's context, precision, and visual character.

How big is that cloud? What direction is it moving? What are the dimensions of the grid? These fundamentals of scale, orientation, and labels—for centuries routine in maps and statistical graphics—are often missing in the colorful images emanating from computer visualizations. In one scholarly compilation (19 articles, 43 authors)



of supercomputer scientific animations, 65% of the 134 color images published had *no scales or labeled dimensions at all* and 22% had partial labels or scales. Only 13% had complete labels and scales.[6]

Restoring quantitative order, my redesign above locates the storm within a three-dimensional tripod of scales and directional arrows. Six small clouds depict a still-land history of the storm and also serve as three-dimensional tick marks for the red time-line, which flows left to right as time passes. The small, still, spatial sequence of images provides a context for the large, moving, temporal sequence above.

Despite the forceful perspective, the original image (left page) is informationally flat. Every element—clock, grid, rectangular domain, cloud, shadow, the brooding School-of-Caravaggio background—is intense and contrasty. In the original, the dominant visual effect (more than half of the pixels) is the orthodontic grid, which lacks quantified scales. The grid resembles the tiled *pavimento* patterns of Renaissance paintings that exaggerate perspective recession and appear in the most improbable circumstances: "... the stable at Bethlehem often boasts a decorative floor, and Saint John finds a small area of tiled paving to stand on in the wilderness."[7] Perhaps an excess of enthusiasm for trendy

Redesigned animation by Edward Tufte and Colleen B. Bushell, with assistance of Matthew Arrott, Polly Baker, and Michael McNeill; scientific data from Robert B. Wilhelmson, Brian F. Jewett, Crystal Shaw, and Louis J. Wicker (Department of Atmospheric Sciences and the National Center for Supercomputing Applications, University of Illinois at Urbana-Champaign); original visualization by Matthew Arrott, Mark Bajuk, Colleen B. Bushell, Jeffrey Thingvold, Jeffery B. Yost, National Center for Supercomputing Applications, University of Illinois at Urbana-Champaign.

[6] Gregory M. Nielson, Bruce Shriver, and Lawrence J. Rosenblum, eds., *Visualization in Scientific Computing* (Los Alamitos, California, 1990). Similarly dismal rates of dequantification were found in 12 other recent compilations of "scientific" visualizations.

[7] Lawrence Wright, *Perspective in Perspective* (London, 1983), p. 82.

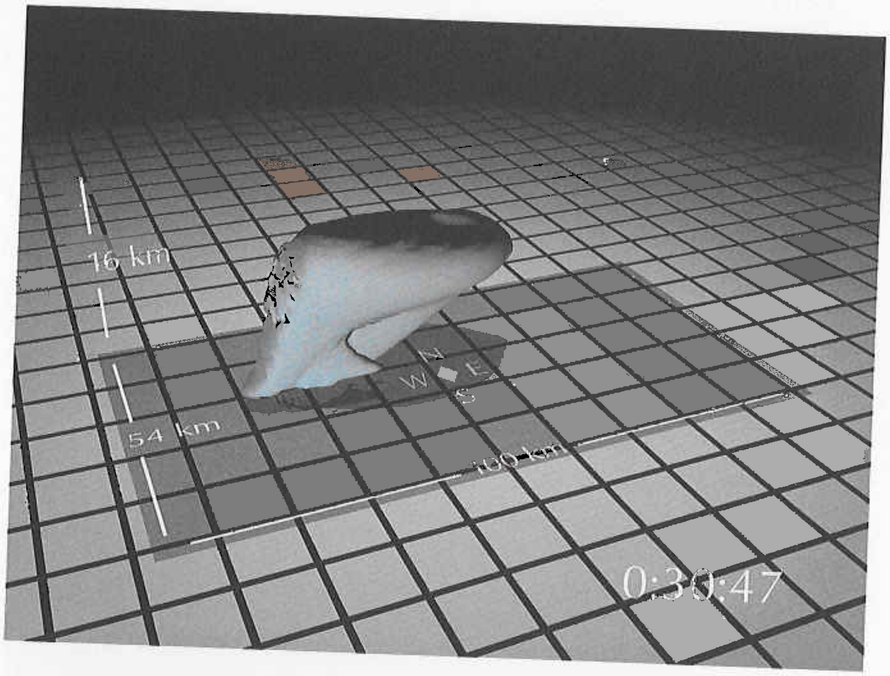


Image from the videotape "Study of a Numerically Modeled Severe Storm," National Center for Supercomputing Applications, University of Illinois at Urbana-Champaign, described in Robert B. Wilhelmson, Brian F. Jewett, Louis J. Wicker, Matthew Arrott, Colleen B. Bushell, Mark Bajuk, Jeffrey Thingvold, and Jeffery B. Yost, "A Study of the Evolution of a Numerically Modeled Severe Storm," *International Journal of Supercomputer Applications*, 4 (Summer 1990), pp. 20–36.

new technologies of three-dimensional display—perspective drawing in the 1500s and supercomputer animations in the 1990s—led to these over-exuberant tiles and grids that disrupt the unity of pictorial content. In this stable at Bethlehem, complete with ox and donkey, the tiles are merely inappropriate and unintentionally humorous; for the storm, however, the tremendous grid aggrandizes geometric perspective.[8]

Rudolf Stahel, *Geburt Christi* (Constance, 1522), 30 by 36 in or 77 by 92 cm. The attribution to Stahel is uncertain.

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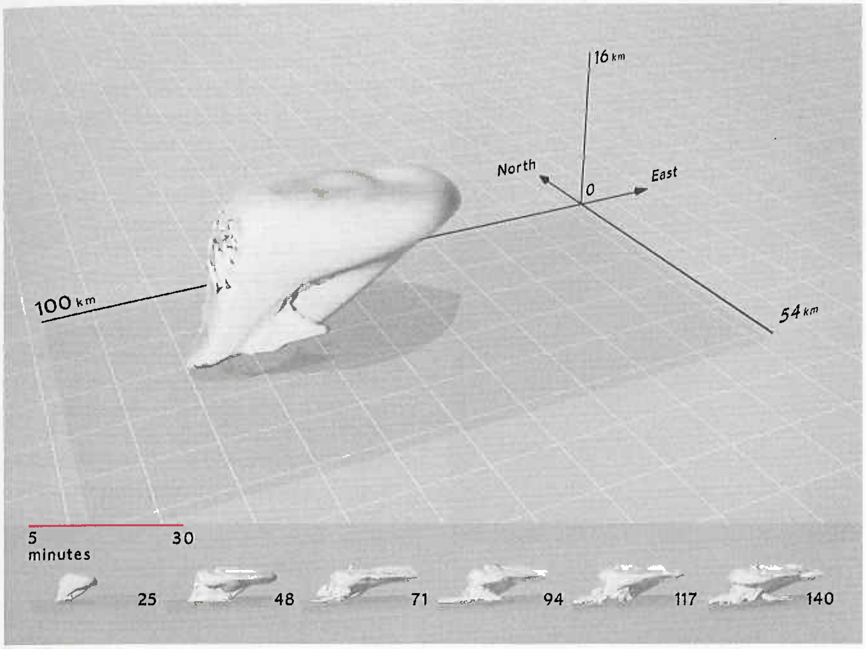
[8] Describing another tiled stable (with walls of receding stone blocks), James Elkins writes: "In Fernando Gallego's *Nativity*, done in the last third of the fifteenth century, the box outshines the Child himself, and all but the most important figures are kept out in order to emphasize its geometric perfection. The chinks are drawn as dark lines, probably in imitation of a preparatory drawing, and their occlusions and jointings are done with as much care, and with more authority, than the divine drama." James Elkins, *The Poetics of Perspective* (Ithaca, New York, 1994), p. 121. Another stable with a tile grid is the Nativity panel by Michael Pacher, *St. Wolfgang Altarpiece* (1471–1481), Church of St. Wolfgang, Austria.



Redesigned animation by Edward Tufte and Colleen B. Bushell, with assistance of Matthew Arrott, Polly Baker, and Michael McNeill; scientific data from Robert B. Wilhelmson, Brian F. Jewett, Crystal Shaw, and Louis J. Wicker (Department of Atmospheric Sciences and the National Center for Supercomputing Applications, University of Illinois at Urbana-Champaign); original visualization by Matthew Arrott, Mark Bajuk, Colleen B. Bushell, Jeffrey Thingvold, Jeffery B. Yost, National Center for Supercomputing Applications, University of Illinois at Urbana-Champaign.

Besides the grid, two other layers of information lie beneath the cloud: a rectangular computational domain and the animation shadow. In cartoons, it is the animation shadow that gets Mickey and Minnie Mouse off the ground visually when they jump up. In this computer scene, one of the several simulated light sources is always above the moving cloud, casting a shadow beneath. Metaphors used in design of scientific visualizations include stages, lights, cameras, movies, cartoons, and, regrettably, television. These enterprises are not distinguished by their commitment to quantitative evidence; better guides for design are excellent maps and statistical graphics.

The original design at far upper left briefly quantifies the storm, as measurement scales and compass directions appear for only 14 seconds (in a grand total of 315 seconds of animation) before vanishing. In the redesign above, the omnipresent tripod might eventually attract attention to an unusual scale: the vertical dimension up into the air is multiplied two-fold compared with the scales down on the ground. Stretching the vertical sometimes helps to depict natural scenes, but such shifts in scaling should be persistently made clear to viewers.

More generally, when scientific images become dequantified, the language of analysis may drift toward credulous descriptions of form, pattern, and configuration—rather than answers to the questions *How many? How often? Where? How much? At what rate?*[9]

Extravagant dequantification is seen in a video flyover of the planet Venus, cooked up from radar data collected during the 1992 Magellan space probe. The vivid animation takes viewers on a rollercoaster tour of steep canyons and soaring mountains, sharply silhouetted against

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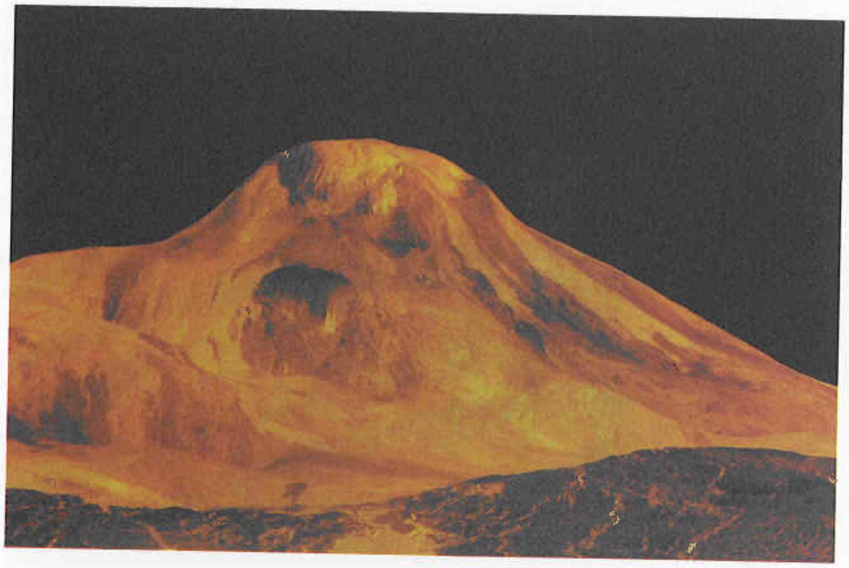
[9] Ironically, one of the first and best visualizations, the movie *Powers of Ten* made by Charles and Ray Eames, deals entirely with the subject of quantity. And an excellent book allows still-land comparisons with the movie; see Philip Morrison, Phylis Morrison, and The Office of Charles and Ray Eames, *Powers of Ten* (New York, 1982). See also a delightful videotape by Wayne Lytle, *The Dangers of Glitziness and Other Visualization Faux Pas* (Cornell Theory Center, 1993); and Al Globus and Eric Raible, "Fourteen Ways to Say Nothing with Scientific Visualization," *Computer* (July 1994), pp. 86–88.



a dark sky. The excitement, however, results from an exaggeration of the vertical scale by 22.5 times! Terrific television but lousy science. David Morrison, the distinguished planetary researcher, had enough:

> This is a call for the formation of a Flat Venus Society. In the face of a media blitz that conveys the impression that Venus is characterized by soaring mountains and deep canyons, a dedicated group is needed to promote the fact that our sister planet is mostly flat, rolling plains.
>
> The beautiful and widely publicized "three-dimensional images" and video "fly-overs" of Venus released by NASA and the Magellan Project at the Jet Propulsion Laboratory all have a vertical exaggeration of 22.5 to 1. This distortion greatly exceeds that normally used even by geologists. . . .
>
> But the reality is different. Take for example, the large shield volcanos of Venus that are usually featured in these videos. They have heights of up to 5 km and widths of several hundred kilometers. It doesn't take a rocket scientist to calculate that the mean slopes are no more than 3°. Yet the public thinks they are precipitous peaks with near-vertical walls rising into a black sky. (A *black* sky? On *Venus*?)
>
> There are a few steep slopes on Venus, and they are important. On the edges of the Ishtar highlands, slopes can approach the angle of repose, providing startling evidence that this plateau is maintained by currently active tectonic forces. But who can tell from the released images?[10]

When such large scaling multipliers are used, viewers might well be shown a Repton-style *before/after* comparison, the natural (flat Venus) and stretched scales (hyped Venus). Otherwise our knowledge is surely imprisoned by the arbitrary technology of image processing and display, just as Matthew Paris, some 750 years ago, was constrained to produce this conspicuously squarish map of Britain. A note on the map, drawn around 1250, explains the distortion: "The whole island should have been longer if only the page had permitted."[11] At least Paris made a clear announcement of the scaling situation right there on his map.

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[10] David Morrison, "Forum: Flat Venus Society Organizes," *EOS* 73 (March 3, 1992); see also Ellen R. Stofan, "Reply," *ibid.* For another critique ("a cartoon volcano") of these images of Venus as made available on a computer network, see Clifford Stoll, *Silicon Snake Oil* (New York, 1995), pp. 83–84. The downloaded images contain no mention of the hyped vertical, and the *sole* documentation is "8000-meter-high Maat Mons on Venus, from NASA's Magellan Spacecraft, courtesy of Jet Propulsion Lab." Large vertical multiples appropriately show mountainous relief in maps depicting entire planets; however, these are *still-land overview* maps, not flyovers close to the surface. In the video of Venus, intense closeness and brisk motion make for a strong impression of height in perspective; a vertical multiplier is not needed to show terrain. In contrast, on still-land globes and maps of the world, mountains without vertical enhancement would be invisible relative to vast latitudinal and longitudinal scales. Finally, hiding a 22.5-fold exaggeration leads to serious errors: a textbook now claims this image of Venus is "how the surface would look to the human eye." Robert Wilson, *Astronomy Through the Ages* (Princeton, 1997), plate 18.

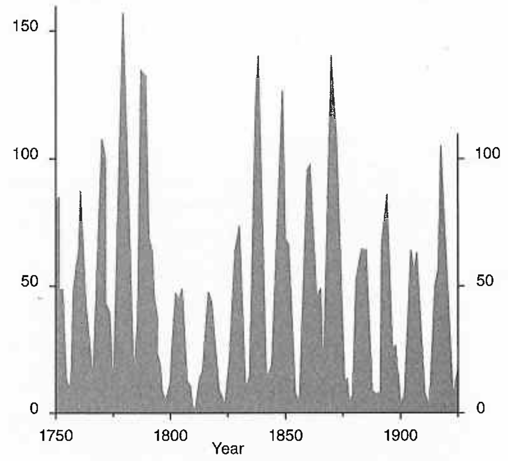
[11] P. D. A. Harvey, "Local and Regional Cartography in Medieval Europe," in J. B. Harley and David Woodward, eds., *The History of Cartography, volume 1: Cartography in Prehistoric, Ancient, and Medieval Europe and the Mediterranean* (Chicago, 1987), p. 496.

Enthusiasts, partisans, and liars have long tinkered with graphical evidence by dequantifying images, selecting and hyping advantageous visual effects, distorting data. Recently, inexpensive computing and ingenious techniques for image processing have provided endless new opportunities for mischief. Arbitrary, transient, one-sided, fractured, undocumented materials have become the great predicament of image making and processing. How are we to assess the integrity of visual evidence? What ethical standards are to be observed in the production of such images?[12] One way to enforce some standard of truth-telling is to insist that the innocent, unprocessed, natural image be shown along with the manipulated image, and, further, that the manipulators and their methods be identified. If images are to be credible, their source and history must be documented. And, if an image is to serve as serious evidence, a more rigorous accounting should reveal the overall pool of images from which the displayed image was selected.

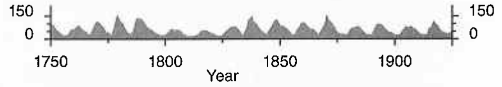
FINALLY, despite the chronic dangers of misrepresentation, appropriate re-expressions or transforms of scales are among the most powerful strategies for exploring data. And in both two- and three-dimensional design, it is often useful to see images and objects at approximately an order of magnitude smaller and larger than actual size.

For example, consider this helpful rescaling, a solution (developed by William Cleveland) to the problem of the aspect ratio in statistical displays. The graph at right shows the number of sunspots by year, 1749 to 1924, moving along in the well-known 11-year cycle. But there is much more in these data than simply rhythms and shapes. Cleveland's good idea is to choose an aspect ratio that centers the absolute values of the slopes of selected line segments on 45°, a technique implemented by iterative computing. Applying this method to the sunspot data yields the graph at lower right, which reveals that cycles tend to rise rapidly and decline slowly, a behavior strongest for cycles with sharp peaks, less strong for medium peaks, and absent for cycles with small peaks.[13] From the original spiky mass of data, fresh and subtle information about quantities emerges with a radiant clarity in the rescaled image.

Number of sunspots each year, 1749–1924



Number of sunspots each year, 1749–1924



[12] The issues raised by image processing are discussed in William J. Mitchell, *The Reconfigured Eye: Visual Truth in the Post-Photographic Era* (Cambridge, Massachusetts, 1992).

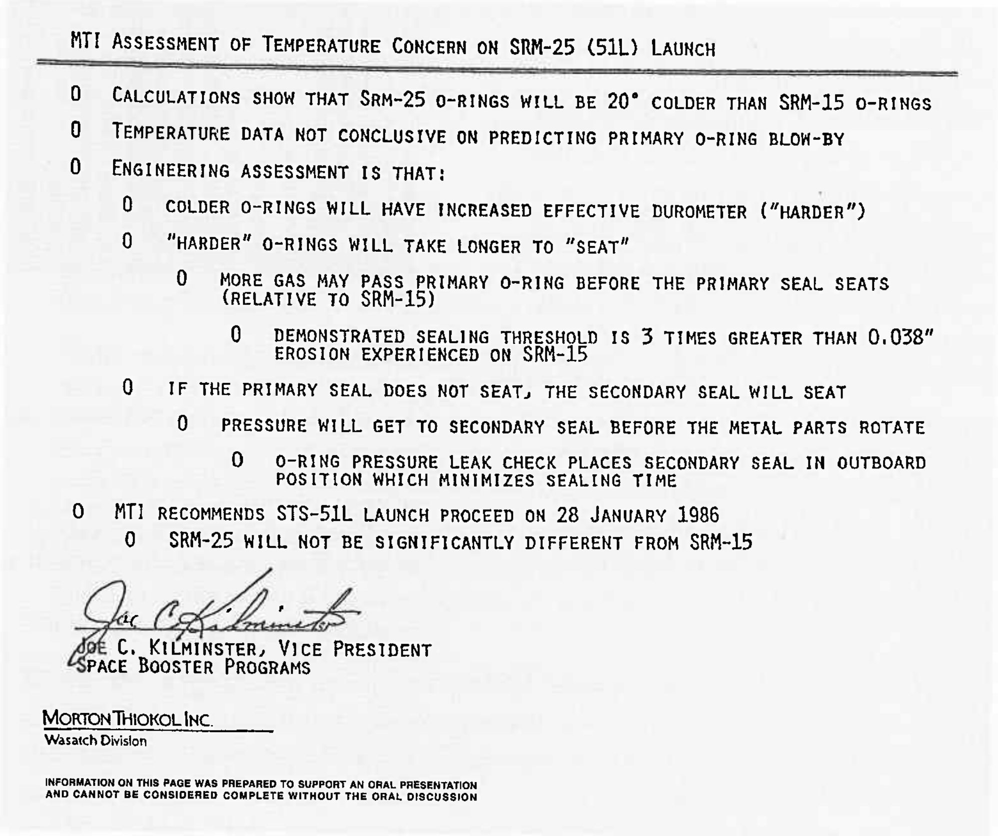
[13] William S. Cleveland, *The Elements of Graphing Data* (Murray Hill, New Jersey, revised edition, 1994), pp. 66–79. Redrawn.

Although we often hear that data speak for themselves, their voices can be soft and sly.

Frederick Mosteller, Stephen E. Fienberg, and Robert E. K. Rourke, *Beginning Statistics with Data Analysis* (Reading, Massachusetts, 1983), p. 234.

Negligent speech doth not only discredit the person of the Speaker, but it discrediteth the opinion of his reason and judgment; it discrediteth the force and uniformity of the matter, and substance.

Ben Jonson, *Timber: or, Discoveries* (London, 1641), first printed in the Folio of 1640, *The Workes . . .*, p. 122 of the section beginning with *Horace his Art of Poetry*.



MTI ASSESSMENT OF TEMPERATURE CONCERN ON SRM-25 (51L) LAUNCH

- CALCULATIONS SHOW THAT SRM-25 O-RINGS WILL BE 20° COLDER THAN SRM-15 O-RINGS
- TEMPERATURE DATA NOT CONCLUSIVE ON PREDICTING PRIMARY O-RING BLOW-BY
- ENGINEERING ASSESSMENT IS THAT:
  - COLDER O-RINGS WILL HAVE INCREASED EFFECTIVE DUROMETER ("HARDER")
  - "HARDER" O-RINGS WILL TAKE LONGER TO "SEAT"
    - MORE GAS MAY PASS PRIMARY O-RING BEFORE THE PRIMARY SEAL SEATS (RELATIVE TO SRM-15)
      - DEMONSTRATED SEALING THRESHOLD IS 3 TIMES GREATER THAN 0.038" EROSION EXPERIENCED ON SRM-15
  - IF THE PRIMARY SEAL DOES NOT SEAT, THE SECONDARY SEAL WILL SEAT
    - PRESSURE WILL GET TO SECONDARY SEAL BEFORE THE METAL PARTS ROTATE
      - O-RING PRESSURE LEAK CHECK PLACES SECONDARY SEAL IN OUTBOARD POSITION WHICH MINIMIZES SEALING TIME
- MTI RECOMMENDS STS-51L LAUNCH PROCEED ON 28 JANUARY 1986
  - SRM-25 WILL NOT BE SIGNIFICANTLY DIFFERENT FROM SRM-15

Joe C Kilminster

JOE C. KILMINSTER, VICE PRESIDENT
SPACE BOOSTER PROGRAMS

MORTON THIOKOL INC.
Wasatch Division

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

The final approval and rationale for the launch of the space shuttle Challenger, faxed by the rocket-maker to NASA the night before the launch. The rocket blew up 12 hours later as a result of cold temperatures.