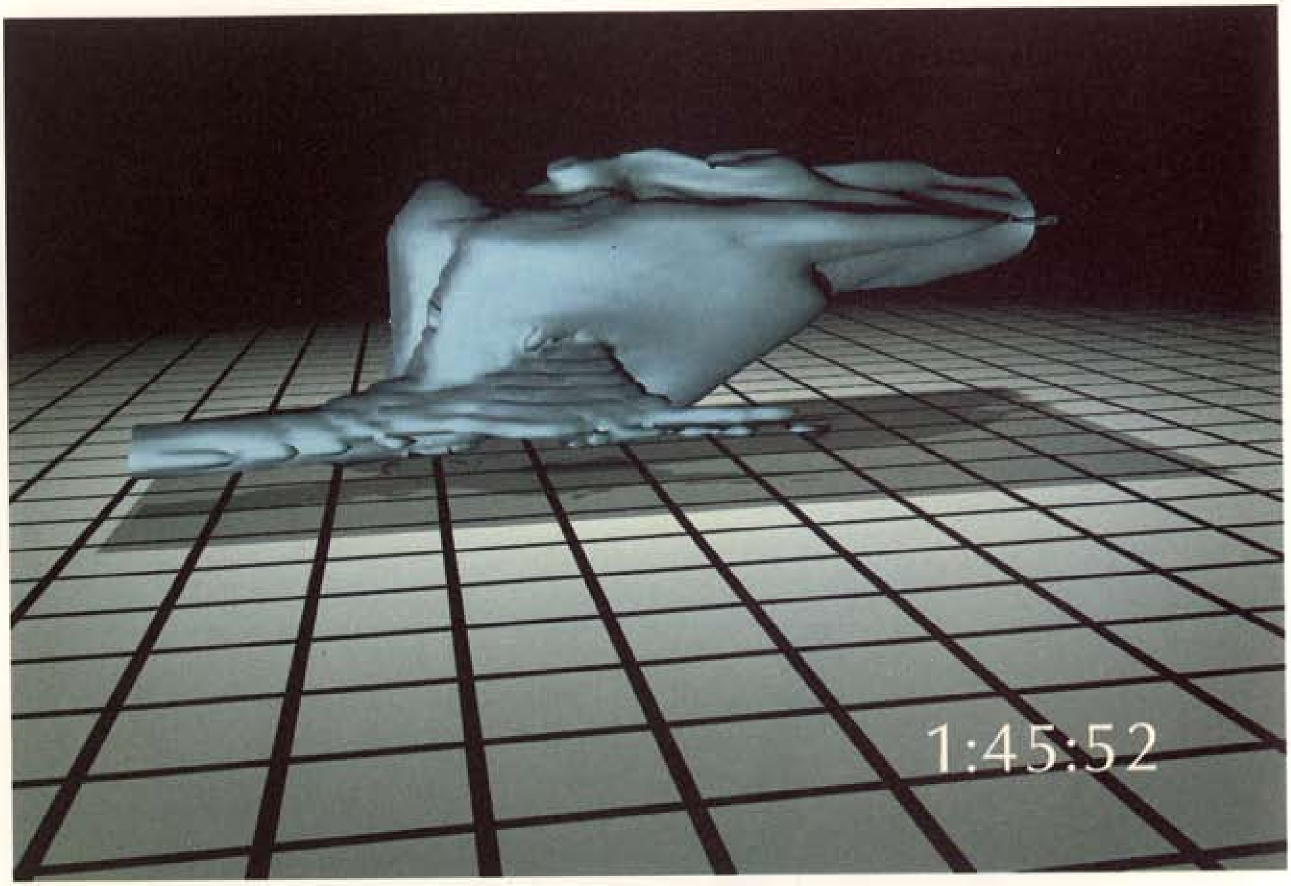
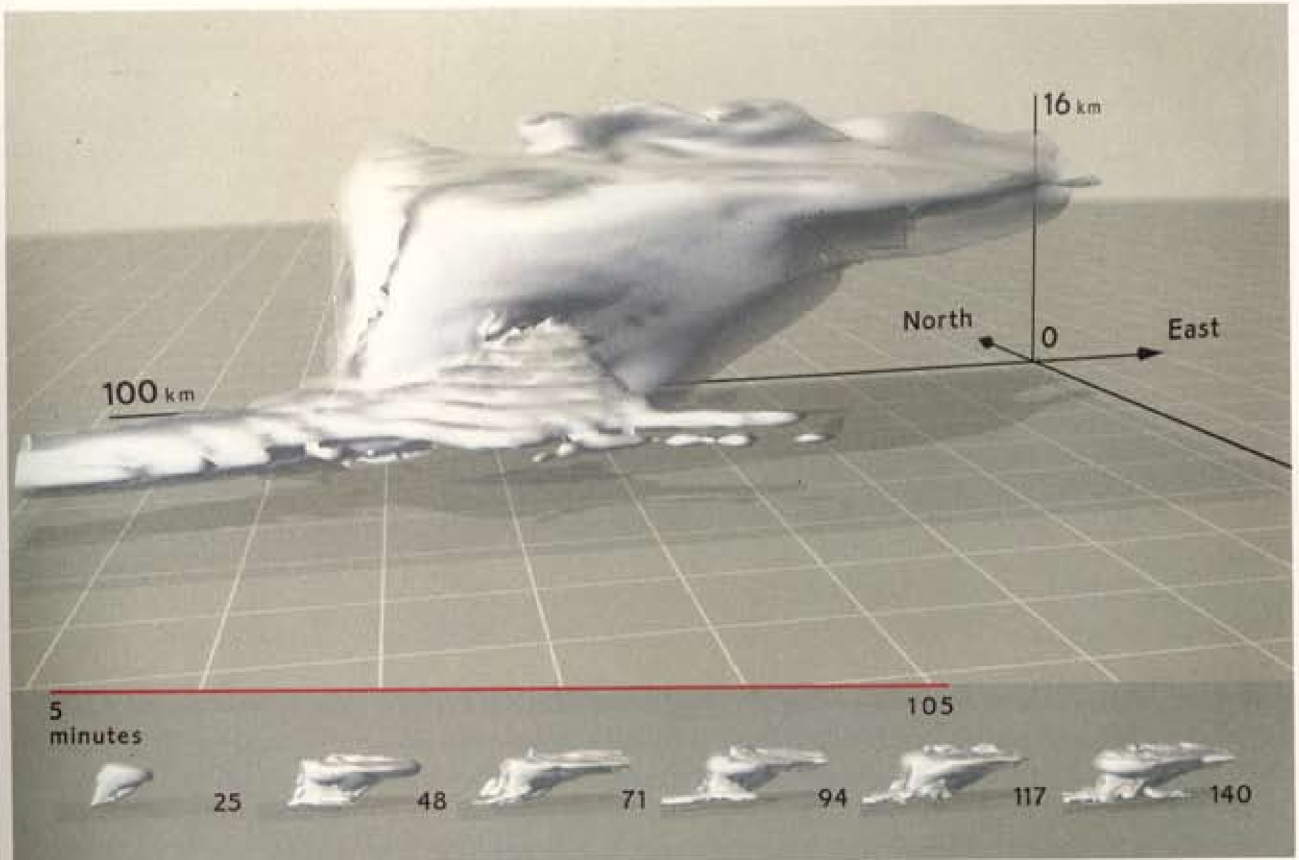


THE dequantification characteristic of art reproductions is also seen in scientific and technical imaging. Shown above is a video frame from a numerical model simulating a thunderstorm. Based on nine time-dependent partial differential equations as well as data gathered during a severe storm in Oklahoma 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)

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.



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.

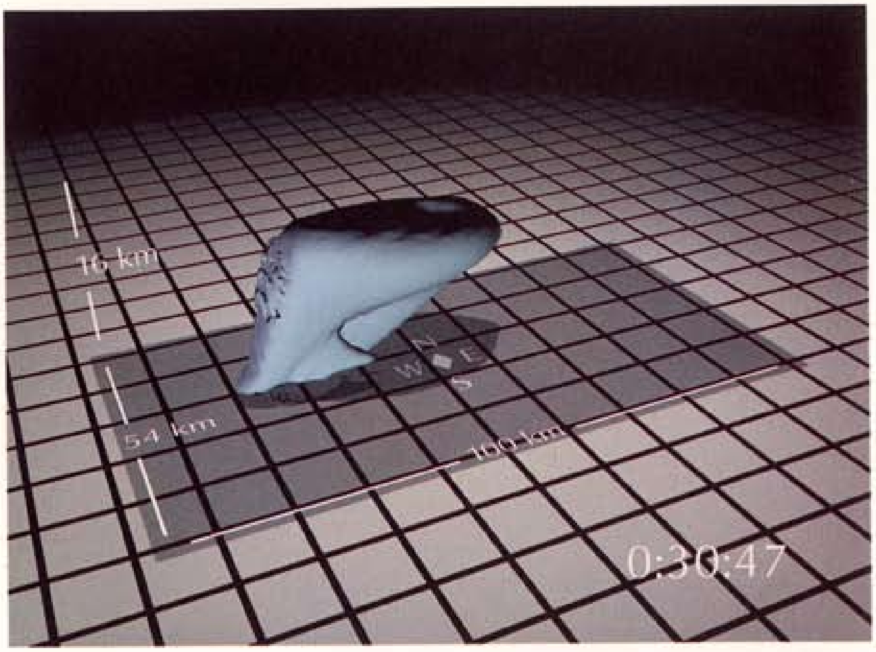
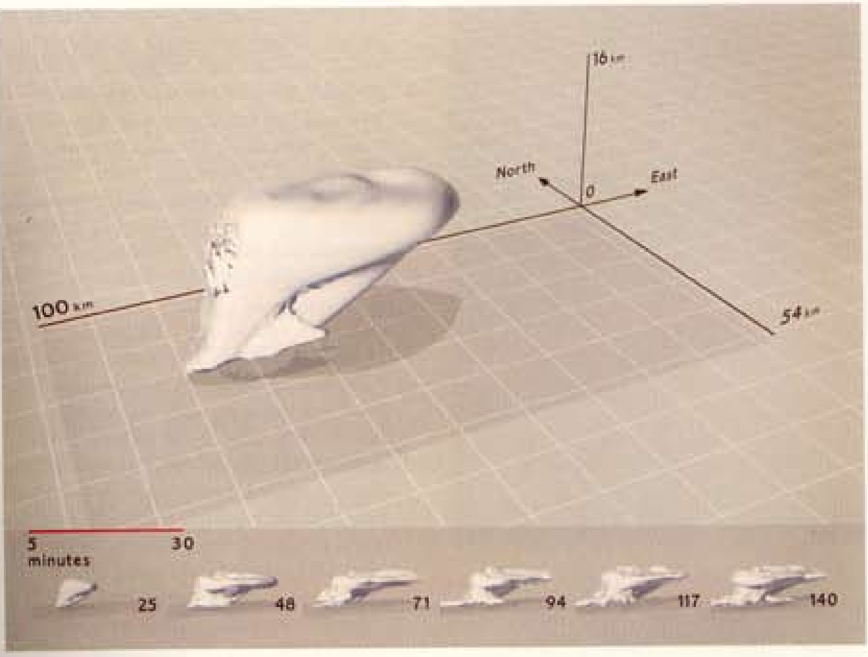


Image from the videotape "Study of a Numerically Modeled Severe Storm," National Center for Supercomputing Applications, University of Illinois at Urbana-Champaign, described in Robert B. Wilhelmson, Brian F. Jewett, Louis J. Wicker, Matthew Arrott, Colleen B. Bushell, Mark Bajuk, Jeffrey Thingvold, 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]

[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.

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



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

[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.