After the Storm:
Considerations for Information Visualization

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Abstract

Scientific visualization strives to present complex concepts and data in graphic forms that maximize information gain for the viewer. In this study, we examine a well-known and highly regarded example of scientific visualization, identifying scenes where principles of graphic design, perception, and cognition suggest improvements. We focus on the identification of primary and supporting elements, provision of cues for spatial and temporal context, effective use of color, and the careful use of animation. The guidelines discussed here generalize and can be useful in a wide variety of applications.

1 Introduction

The animation **Study of a Numerically Modeled Severe Storm** is generally well-known within the scientific visualization community. When it was first introduced, this video was shown so widely and with such frequency that it was referred to as the "teapot of scientific visualization"[1] [3]. Figure 1 is a representative scene from the original 3-minute video. The animation is an example from among the best of that particular genre of scientific visualization. It features full storyboarding, well-chosen representations, high-quality rendering, and professional narration.

In this study, we revisit the storm to discuss what we would do differently if we were to make that video again. Our purpose is to demonstrate several principles of effective information presentation, drawing from the fields of graphic design and visual perception. The storm video was selected for this project because it is well known and generally well regarded. This paper is not an exercise in finding fault with bad visualization. It is a study in optimization and discusses how to make a good thing better.

The original video was produced using the modeling, animation, and rendering capabilities of Wavefront's Advanced Visualizer [11]. To facilitate comparison, most

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[1] The geometry for a particular ceramic teapot has been available to computer graphics researchers since the early days of the field. New rendering techniques were often demonstrated by using this teapot as a test object, making the teapot ubiquitous in the field of computer graphics.

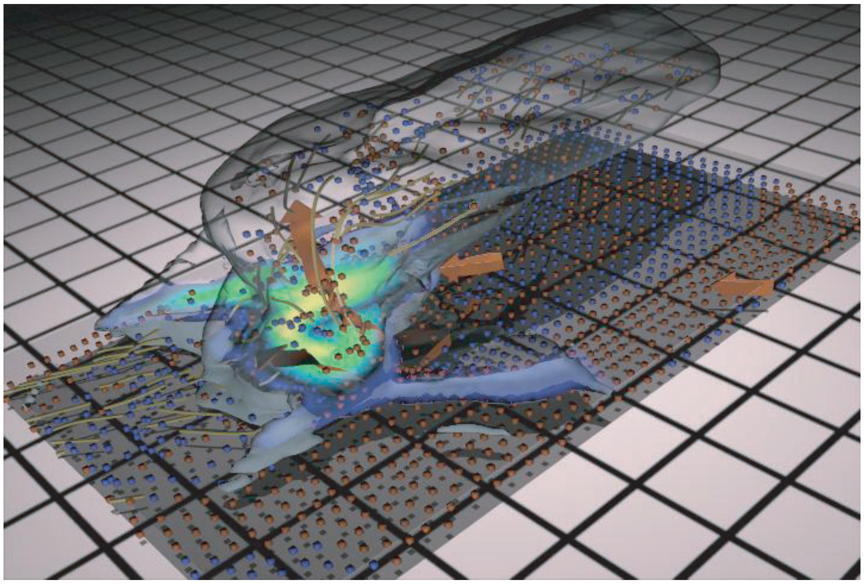

Figure 1: An image from the original thunderstorm video.

of the current work was done with the same software. However, many of the points discussed in this paper apply to interactive visualization tools as well.

This study was carried out in collaboration with information design specialist Edward Tufte [8][9] from Yale University and with NCSA visualization professionals Colleen Bushell, Matthew Arrott, and Michael McNeill. The simulation is the work of Robert B. Wilhelmson and his research team, notably Lou Wicker, Brian Jewett, and Crystal Shaw.

The original video animation [12] was produced from data generated by a simulation run on a CRAY supercomputer at NCSA. The simulation models the genesis and lifetime of a severe storm by solving a set of time-dependent equations over a collection of regularly spaced grid points in a three-dimensional rectangular region of space. The simulation's grid points are initialized with measures of temperature, pressure, moisture, and wind velocity taken at the origination of a storm that crossed Oklahmoma and Texas for two-and-a-half hours on April 3, 1964. That storm spawned a tornado that killed 7 people, injured 111, and did $15 million in damage.

2 Overall Spatial Context

In the original visualization, pictured in Fig. 1 and Fig. 3, a grid serves to measure and mark the space through which the storm travels. The video's narration indicates that the grid lines occur at 10 km intervals. The shape of the cloud is projected to the ground plane, creating a "shadow". This tells us something about the overall shape of the cloud. More importantly, the shadow serves to anchor the cloud to the ground. The footprint of the computational space is shown by the darkened box. In the animation, the box and cloud travel over the grid; the grid provides the visual reference needed to indicate the direction and speed of movement.

In the new version, elements of the scene were revised to reflect their primary and supporting roles. The grid and computational box are both supporting elements, included as a backdrop to provide context for the primary element, the cloud. The new image, shown in Fig. 2, uses much narrower grid lines and less contrast in coloring. This presents a "lighter" rendition of the background layer, appropriate to its role.

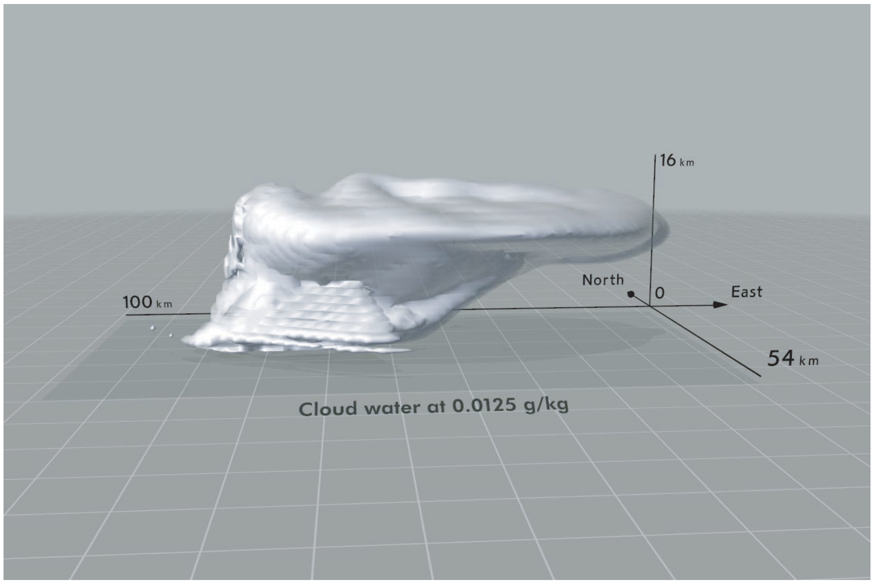

Figure 2: The new grid is lighter in weight and in color.

Just-noticeable differences refers to the minimal variation in a parameter that is required for perception of the variation [6]. In computer-generated visuals, a 7% difference in luminance between noncontiguous patches is perceptible; for adjacent patches, a luminance difference as small as 2% is perceptible [7]. That concept was used as a design principle in re-coloring of the grid, the computational box, and the shadow. As shown in Fig. 2, the box is just slightly darker than the ground plane, and the shadow just slightly darker than the box. The grid lines are close in color to the ground plane.

Too high a contrast between neighboring areas can cause the lighter area to glow or seem overly bright at the line of adjacency (a phenomenon called *simultaneous contrast*.) The hard edge of light to dark can also "crawl" in a distracting manner in animated video. Using minimal contrast for ground, box, shadow, and grid avoids these problems. Also, this strategy opens up the possibility of incorporating additional information. For example, the computational rectangle in the new version is light enough that contour lines – perhaps showing temperature ranges in the ground plane – could be drawn in a dark color and would be visible against the box.

The original animation relied on an opening sequence and the narration to provide information about the actual size of the storm. Figure 2 adds a set of coordinate axes and labels to show that the compuational space of the simulated storm measures 100 x 54 x 16 kilometers. Careful reading of the axes reveals that the scaling in the vertical dimension is not the same as the East and West directions. In both the *before* and *after* versions, it has been stretched to twice its actual height, to show the activity in the interior of the cloud more clearly.

The *after* version, like the *before*, expects the viewer to intuit a sense of size from the quantitative dimensions. This is certainly adequate for researchers in the field of atmospheric sciences and for others accustomed to working with such distance information. But the original storm video was intended for a wide audience, so it would be useful to provide visual cues to support comparison between the storm and more familiar objects. For example, at 16 km the storm is almost twice as tall as Mt. Everest. And the 100 km width of the computational space is roughly equal to 60 miles, or about the distance travelled in an hour of highway driving. Visual expressions of these cues would be useful additions.

The set of coordinate axes in the *after* version could also be used to explicitly communicate about the resolution of the simulation data. Horizontal separation between grid points is 1 km and vertical separation is 0.5 km, for a data cube of 101 x 55 x 31. Hash marks could be used on the axes to show the resolution. While it's generally not necessary to retain this detail throughout the entire animation, it is important to be explicit about data resolution at some point during the visualization.

3 Revealing Inner Detail

The original storm video reveals considerable detail about the simulated storm by combining a variety of representations. For example, the particles in Fig. 1 show air movement. The particles colored orange (a warm color) represent rising air and particles colored in blue (a cool color) show falling air. Information about data values inside the cloud is also shown by coloring a slice of the cloud, analogous to the radar reflectivity maps shown on TV weather forecasts. In Fig. 1, the slice remains embedded in the cloud. In another scene, the slice is extracted and shown separately (see Fig. 3). The stripe on the cloud locates the missing slice. A color bar provides the legend for interpreting the slice colors. The small white gauge on the color bar slides up and down and shows, at each frame of the animation, the maximum data value occuring in the slice.

A number of changes were made for the *after* version of this scene. The white box around the slice in the original is too prominent, and is unecessary anyway. The gauge for the maximum data value indicates the maximum for the current timestep. To grasp the changing pattern of maximum values over time the user must remember and mentally integrate the positions of the indicator. Given the well-known limitations of human short-term memory, visualizations should strive to reduce this kind of mental load.

With this in mind, we modified this scene to produce the picture in Fig. 4. Two

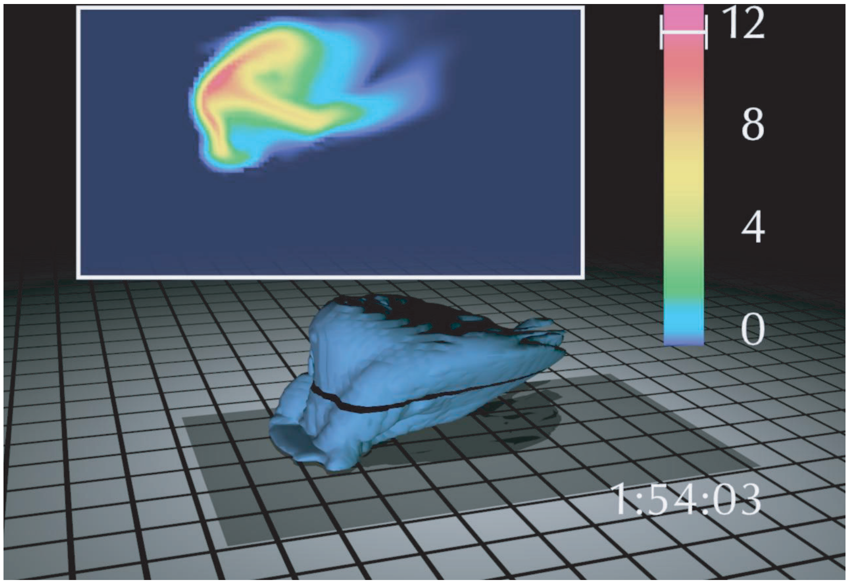

Figure 3: A scene from the *before* version, showing details of an inner slice.

slices are extracted, revealing inner structure at both lower and upper levels of the cloud. The maximum-value indicator is replaced by a graph that shows the history of maximum values for each of the slices. Labels clarify just what it is that we are looking at – the variable of interest (rainwater concentration) and the physical location of the slices.

Geometry for the actual graph lines could be improved, since the width of each line is somewhat dependent on the line's slope. We could have used the actual data points as the centerline through a constant-width tube to improve this. In screen-based applications where lines are being drawn from screen pixel to screen pixel, one way to mitigate slope-dependencies is to draw multiple lines. Draw one line centered on the actual data points. Draw additional lines offset slightly from the data points. Using 6 additional lines offset in a hexagonal pattern often works well [2].

Proximity has been shown to be effective in graphical displays when multiple information elements must be integrated [1]. This principle guides placement of the colorbar and its labels. The purpose of the colorbar is to support interpretation of the colors in the slices, so it is placed close to the slices themselves.

4 Color

Personal preference guided some of the color changes made in the *after* version of the storm study. In particular, the use of a light background, a light cloud, and grid lines that are lighter than the ground plane were primarily matters of personal opinion. As a general guideline, "natural" colors should be used. Many visualizations deal with unobservable phenomena or abstractions where the concept of natural colors does

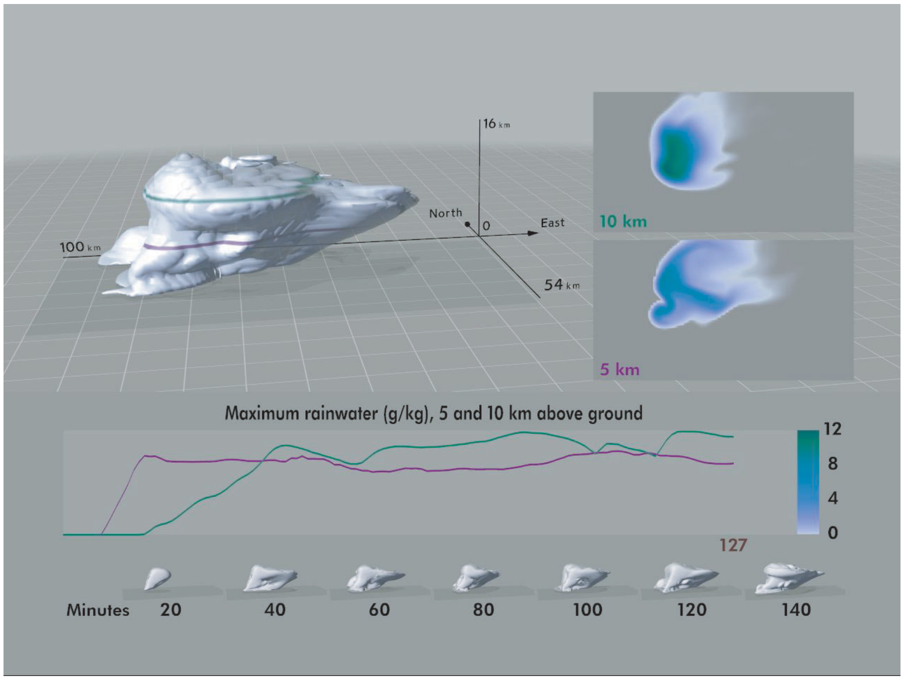

Figure 4: The *after* version uses a continuous-hue colormap, two slices, and a graph.

not apply. However, in visual studies that deal with physical phenomena observed in our everyday world, using colors that suggest the natural object helps the viewer make the mental link between image and object [5][9].

In nature, storm clouds can appear either dark or light. In the original video, the dark coloring of the scene contributes to a "dark and stormy" mood. This was appropriate to the video's purpose of communicating to a general audience about supercomputer modeling of severe weather phenomena. The "light" version takes a more distant, perhaps dispassionate, view of the storm.

The color mapping used for the slice in the original version is a modified version of a *rainbow* palette, using a wide range of hue. For many users of visualization, a rainbow is the first palette they think to employ and the rainbow palette is the default in many visualization tools. The advisability of using such a palette depends, in part, on the intent of the analysis task. For example, if the goal is to identify the quantitative data value at a particular point on the slice, using hues that are easily discriminated and easily matched to the colorbar is necessary. It is best to use only a small set of colors for this task. When more than 4-7 colors are used, color discrimination is unreliable [7].

Alternatively, if the user's task is to determine the overall structure of the data slice, a many-hued palette like the rainbow can be ineffective or misleading [10]. The rainbow of colors introduces discontinuities to the image that might not be present in the data. For example, the edge from yellow to green in Fig. 3 suggests a distinct change in the underlying data, which may or may not be there. When looking for overall structure, a visually continuous colormap can be more effective. Using a small range of hues with smooth transition, or a single hue and changing value, provides more effective support for the user in this task.

Illustrating these points, Fig. 5 shows a slice from the cloud using a variety of colormaps. The upper left image employs a colormap close to the original storm video. The upper right image uses the same curve for hue, but its value curve is constant and its saturation curve increases sharply. The saturation curve in this colormap mimics the cumulative frequency distribution of the data slice. The resultant coloring brings out many of the low values that are lost in the original palette.

Both of the palettes in the top row use a fairly broad range of hue, leading to discontinuities in the image where the colormap changes, for example, from green to yellow and from yellow to orange. Using a single hue avoids these discontinuities. However, a straight grayscale colormap is not necessarily the best answer. Most of the slice's structure is hidden by the grayscale colormap (middle row, left image) of Fig. 5. On the right, we use a single hue but ramp through value quickly to bring out the low data values, and use saturation to vary the high-valued upper range of the colormap. The 2 images in the bottom row again use hue to convey differences in the data, but with a restricted range. The color scale on the right, a sequence of red-orange-yellow-white, is commonly referred to as a *fire* palette. This colormap has the advantage in that it is ordered by perceived brightness, progressing from dark to light.

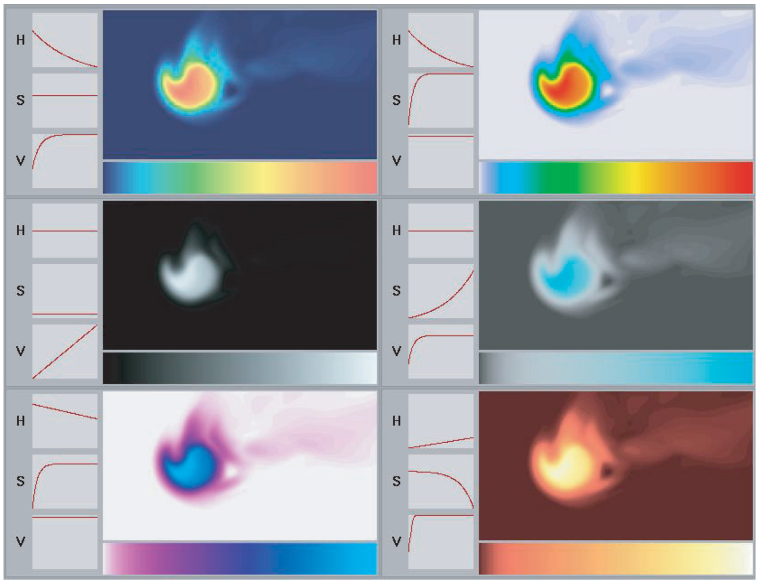

Figure 5: A single slice displayed with a variety of color mappings.

Color choice in computer-generated visualization must also consider the background and expectations of the intended viewer. Many fields, such as chemistry and seismology, have long-established traditions for the meanings of particular colors; the meteorological community is developing such guidelines for presenting weather information [4]. It was anticipated that the audience for the original storm visualization would be familiar with rainbow-colored TV radar maps, and so a rainbow palette was used to color the slice.

Color in the *after* version is also used to tie related elements of the scene together, specifically the slices, their reference locations within the cloud, and the appropriate graph lines. Empirical studies of the capability of various design strategies to support integration of related pieces of information bear out the intuition that color is effective in grouping items together [1].

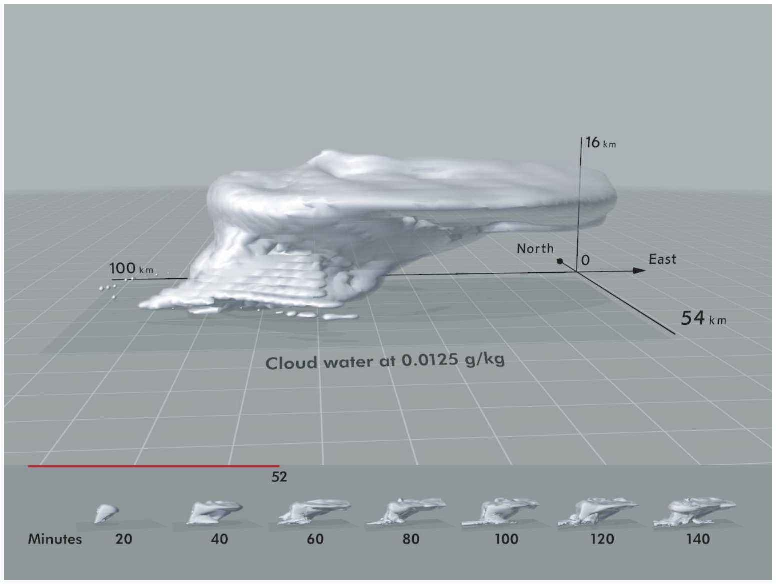

Figure 6: A timeline shows where we are in the context of the overall story.

5 Animation

Movement of elements in the visual field commands attention, possbily more than any other visual cue. In the original storm video, the cloud water surface changes shape as the storm cell develops, and the cloud itself travels across the grid to show the path and the speed of the storm. Appropriately, motion in these elements dominates the scene. A couple of secondary elements are also quite active, which is inappropriate and somewhat distracting. The *after* version reduces the level of activity in these elements.

As noted above, the original slice scene used a white slider, jumping up and down on the colorbar to show the current maximum value from the slice. In the *after* version, the indicator is replaced by the graph.

The *before* version also includes a clock in the lower-right corner, frenetically ticking off the hours, minutes, and even seconds of the storm evolution (see Fig. 3). In the *after* version, we stretch a timeline across the lower part of the image (see

Fig. 6 and also Fig. 4.) The timeline's small clouds serve as anchor points and give, in miniature, a coarse overview of the changes in size and shape of the storm. The small clouds in Fig. 6 show how little variation there is in the cloud water shape beyond the early stages of the storm's development; there is somewhat more variability in rain water, as shown in the small clouds in Fig. 4.

The red time marker advances from left to right to show the current time within the overall temporal span of the simulation. For example, at 52 minutes, we are a bit more than one-third through the life of the storm. Using bright red for the timeline sets the line off and makes it easy to locate and monitor, even while still concentrating on the animation of the cloud.

As discussed earlier, the high contrast between the grid lines and the ground in the *before* version can lead to a distracting "crawl" effect in animated video. The *after* version reduces the luminance difference between these two elements. The *after* version also uses narrow grid lines, with the width of the lines chosen carefully. Very narrow lines – lines that are only the width of a single pixel in an image – can produce severe jittering in video. The grid lines in the *after* version are quite narrow, but they are still wide enough to hold up well and appear steady in video animation.

6 Summary

In this study, we subjected the well-known thunderstorm video to a critical eye, identifying scenes where principles of graphic design, perception, and cognition suggest improvements. Several of those scenes have been discussed and illustrated in this paper. Our changes focus on identifying primary and supporting elements, providing adequate cues for spatial and temporal context, using color effectively, and reducing distraction caused by animated elements. While this paper represents but one tour through the space of possibilities for presenting information, the guidelines discussed here generalize and can be useful in a wide variety of applications.

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