Visualization of Fuzzy Data Using Generalized Animation*

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Abstract
In this paper, we present methods for visualization of fuzzy data based on the sensitivity of the human visual system to motion and dynamic changes and the ease with which electronic display devices can change their display. The methods presented include taking an otherwise static image and displaying in an animation loop either its segmented components or a series of blurred versions of the whole image. This approach was applied to sea-surface temperature data and was found to be effective in showing fuzzy details embedded in the data and in drawing the viewer's attention. This approach and methods could play a significant role in the display of browse products for massive data and information systems.

1: Introduction
Data represented in a visual form is used for visual analysis and for scanning for the existence of desired features. Researchers and analysts examining data displays would like to detect regions of specified values (e.g., high, medium, or low), their locations, and shapes. The problem of detecting the existence of patterns, locations, and shapes is difficult, especially in low-resolution browse sets where one would like to scan large quantities of fuzzy data as fast as possible and detect features efficiently. Fast scanning of large amounts of data is facilitated by the use of computer devices and displays. Detection of features present in fuzzy data is difficult not only because the data is fuzzy but also because current display devices are inefficient. However, in contrast with the printed page, electronic display devices are flexible in the sense that they are able to change the displayed information rather quickly. If one could use this flexibility to feed information through preattentive visual processes, one would enable the user to perceive the desired information quickly and efficiently.

The visual detection of moving objects is a preattentive process occurring relatively quickly. Traditionally, animation is usually employed to follow time development of data or to watch three-dimensional structure of objects (by viewing objects rotating in space). As noted by Livingstone [1988], the sensitivity of the visual system to "color contrast, movement, and stereopsis suggests that hard-to-see objects can be made more visible by introducing movement (by moving the object or the observer) or stereopsis (by simultaneously viewing two images of the same scene taken from different positions)."

In this work, animation is used for two purposes. First, animation is employed to enhance the visibility of features embedded in the data by creating changes in the displayed data during the time of viewing rather than by moving the data relative to the observer. The second purpose of using animation in this work is to draw the attention of the viewer to features present in the data. In these contexts, the notion of motion is generalized (besides linear motion of the whole image) to any changes occurring on the screen during viewing time. These changes could include linear or rotational motion of parts of the image displayed on the screen, changes in size and/or color of objects, blurring and sharpening, or any additional information plotted progressively on the screen. Such changes could be created from the original fuzzy data set and, if this is the case, they do not require the storage and retrieval of additional data.

2: An Animation Primer
Detecting motion seems to be primordial and one of the most important visual mechanisms in many life forms. Whether this property comes from an adaptation geared to detecting predator or prey, or it is a common mechanism developed together with other abilities such

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as stereo vision is a matter of speculation. It has been found that observing motion triggers a set of fast and effective mechanisms in the visual system that allow the efficient detection of the moving features. In this work, we use animation to enable the user to exploit these mechanisms to detect quickly patterns and features embedded in the data. This approach should allow the detection of fuzzy structures in low-resolution browse sets and direct the attention of the viewer to features embedded in the data.

The projection of an animated sequence creates the illusion of motion, or apparent motion. To see the apparent motion, the observer must connect features present in successive frames in a process called correspondence. Ramachandran and Anstis [1986] have summarized facts about the correspondence process. To extract salient features during animation, the visual system prefers to use low-spatial-frequency structures, like blobs of brightness and darkness, and texture rather than detailed shape outlines and edges. To connect features appearing in successive frames (correspondence), the visual system assumes that the world has order and takes shortcuts in perceiving the situation. It basically uses what makes sense consistent with life experience. These mechanisms include the following assumptions:

- Objects move in straight lines rather than change direction abruptly [Ramachandran and Anstis, 1986]

- Objects are rigid and small details are not compared in successive frames if the global object is perceived [Ramachandran and Anstis, 1986; S. Ullman, M. Riley, and D. Marr, described in Marr, 1982]

- Moving objects cover and uncover portions of the background. Objects are conserved [Ramachandran and Anstis, 1986]

These mechanisms are so strong that they can lead sometimes to visual illusions that persist even if the viewers’ logical minds disagree [Ullman, 1979; Ramachandran and Anstis, 1986; Gershon, unpublished results]. For example, two objects may correspond to each other even if they have different visible shapes. Or, two objects of distinctly different sizes are perceived as shrinking and expanding rather than trading places when they are in fact exchanging places. These facts “violate” the rules of rigidity and the conservation of objects. Based on these observations, one would like, then, to add the following rule to the ones mentioned above:

- Usually, the simplest explanation is taken most seriously of all (e.g., shrinking and expanding could be taken more seriously than linear motion).

As for conditions that enhance the detection of moving objects, motion and depth perceptions are sensitive to brightness rather than hue contrast [Livingstone, 1988].

3: Methods

The methods developed in this work enhance the visibility of fuzzy structures in an image by introducing dynamics into an otherwise static display. The dynamic changes include displaying different ranges of the data separately or displaying the data with varying degrees of sharpness. These methods are described in the following paragraphs.

3.1: Animation of Segmented Components

In this method, a single data set is classified into a discrete number of groups determined, for example, by the value of each point. In such an example, if the range of data values is from 0 to 30, the data could be distributed into 30 groups, where the first one consists of all data points in the range of 29 to 30, the second one consists of the points with values in the range of 28 to 30, and so on. The data corresponding to each region is displayed separately in an animation loop. If these regions are displayed from high to low values and then back from low to high, the resulting dynamic display consists of expanding and shrinking structures (given that the structures are determined by the data values). In this animation loop, the range of displayed data values of a particular data set could be changed, for example, by varying the minimum (and/or maximum) value of the data to be visualized during the animation sequence. The results of this type of animation could be very effective in perceiving the data values and the location and shapes of structures embedded in the data. If the background color for representing the data values outside the threshold is black, the brightness contrast between the displayed regions and the background should increase the effectiveness of this procedure. To further enhance the perception of the data structures, the entire range of the color table in a frame could be made to cover only the range of the displayed data in the frame. This could create a dynamic change in the color of the structures during viewing time. The storage of the data could be arranged so that, for example, high values of the data are transmitted first, thus making the best use of a limited communications bandwidth. To further enhance the perception of structure, data values, locations, and shapes, 3-D surface views (with color and with or without shading) could be generated for the displayed range of each frame.
3.2: Animation of Blurred Versions of the Data

In this method, a series of increasingly blurred versions of a single data set are created and displayed in turn in an animation loop. The blurred images could be created by generating lower resolution versions of the data (by subsampling, for example) or by using image-processing techniques, such as replacing the pixel value by its local average, to blur the original image. If the series containing the original image and the increasingly blurred versions is displayed in a "rocking" animation mode (from the sharpest to the blurriest and then back from the blurriest to the sharpest), the features in the data should dynamically appear or disappear from the screen. Under these conditions the features should look clearer and the changes should catch the viewer's attention. This mode could take advantage of the finite rate of network transmission. In these situations, the lower resolution pixels are sent first, followed by pixels that improve the resolution of the image.

3.3: Correlation of Multiple Data Sets Using Animation

A scientist or analyst wishing to correlate visually two or more data sets of the same geographical area could do this by quickly flipping the displayed data sets from one to another. In some situations, detection of correlated structures could be enhanced by shifting one image relative to the other, thus creating an illusion of motion between structures present at the same location on the images. This illusion of linear motion could activate the preattentive motion detection processes and thus help in detecting the correlation. This correlation method is similar to the method of flashing used in astronomical images to follow time development of two instances.

3.4: Sea-Surface-Temperature Data Acquisition

Sea Surface Temperature (SST) is measured either by recording radiation emitted by the ocean surface as collected by radiometers residing on satellites or by in situ measurements by thermometers residing on ships or buoys. A global blended SST data set generated from these two types of measurements was created by R. Reynolds [1988]. The data used is monthly blended average SST as a function of latitude (-90 to 90°) and longitude (0 to 360°) coordinates and time.

4: Results

The approaches discussed in the Methods section were implemented and applied to the global blended SST data set. The data consists of sea-surface temperature as a function of latitude and longitude for the month of January 1984. The data used in this work was generated from the original data set by subsampling (only 1 out of 16 data points were kept), yielding a low-resolution browse set. The structures in this data are areas of high-sea-surface temperature (24 - 31 °C) in the equatorial region. We have performed an initial evaluation of the effectiveness of the three methods discussed in Section 3 by showing the displays to a group of about twenty viewers. Most of this audience (90%) has perceived the existence of structures, their locations and shapes better than in the static display of the data.

For the method of Animation of Segmented Components described in Section 3.1, the displayed range is 24 to 31 °C. Each image represents the points lying in a progressively larger range, e.g., 30-31, 29-31, 28-31 °C, etc. Three images of an animation sequence created using this method are presented in figures 1a - 1c. The range of the color scale is different for each image. For example, for the image representing values from 30 to 31 °C, the color scale covers values from 30 to 31 °C, while the black represents values of temperature below 30 °C. For the image representing values from 26 to 31 °C, the color scale covers values from 26 to 31 °C, while the black represents values of temperature below 26 °C. A total of seven images was included in an animation-loop run in a rocking fashion. This type of rocking consists of presenting the narrow range (30-31 °C) first, then 29-31 °C, down to the broadest range (24-31 °C) and back again to the high, narrow range (30-31 °C). Viewing the animation, the locations, shapes and the relative values of this high-temperature part of the data (24 to 31 °C) stand out immediately and their perception is done effortlessly as compared with viewing the original static image by itself.

For the method of Animation of Blurred Versions of the Data, discussed in Section 3.2, the data was displayed using a simple color scale (blue and red represent the lowest and the highest data values respectively). The SST browse data (1/16 of the volume of the original data) was blurred progressively using local averaging (each of the pixels of the subsampled data replaced by its local average) [Blackadar, 1990]. This image was then used to create the next image of the animation set by further blurring, and so on. The set of six blurred images were then displayed using animation. Examples of images included in the animation loop are displayed in figures 2a - 2c. Progressing through the animation set in both directions produced an effect of blurring and sharpening of the details present in the original browse image. This animation was found to make the structures embedded in the data more visible and to draw the viewer's attention to them.
Figure 1a: SST data (January 1984) in 30 - 31°C range (frame 1 of the segmented-components loop).

Figure 1b: SST data (January 1984) in 27 - 31°C range (frame 4 of the segmented-components loop).

Figure 1c: SST data (January 1984) in 24 - 31°C range (frame 7 of the segmented-components loop).

Figure 2a: SST data (January 1984) reduced by a factor of 1/16 (frame 1 of the blurred-versions loop).

Figure 2b: SST data of fig. 2a smoothed by 40 passes (frame 3 of the blurred-versions loop).

Figure 2c: SST data of fig. 2a smoothed by 100 passes (frame 6 of the blurred-versions loop).

(See color plates, p. CP-30.)
For the method of Correlation of Multiple Data Sets Using Animation, described in Section 3.3, two images were used: SST from January 1984 and from January 1985. The latter was used instead of a second quantity such as pressure on the sea surface. Since, there is a shift of the features embedded in the SST data over time, no additional pixel shift was needed. Flashing the images one after the other created a suitable environment for visually correlating structures appearing in both images.

5: Discussion

The methods presented in this paper are designed to use the awareness to dynamic change and motion of the human visual system for two purposes: (1) to improve the visibility of fuzzy structures embedded in the data, and (2) to draw the attention of the viewer to the details presented on the screen. The resulting displays improve the efficiency and speed of browsing through low- as well as high-resolution data. The motion of motion is extended to include any change on the screen occurring during the viewing time. This extended notion includes changes in the shape, size, sharpness, color, and orientation of the objects contained in the image. To increase the accuracy and speed of perceiving the required information embedded in the data, it is advantageous to use multiple (and complementary) sources of information such as motion and color. Using multiple visual cues in displaying low-resolution browse data could be crucial to their usefulness and effectiveness.

When watching the motion of small details, one has to be careful not to deflect the viewer’s attention to irrelevant details. Thus, for example, when viewing geographical data, the outlines of the continents should not be very pronounced in cases where they change during the animation. Otherwise, the motion of the continents, or the oceans, will be perceived without watching the motion of the smaller features. This is a consequence of one of the shortcuts employed by the visual system mentioned above that small details are not compared in successive frames if the global object is perceived.

With an appropriate structuring of the data storage, the animation process could be used in situations where the bandwidth of data transmission is low. For example, data could be transmitted discriminatorily, first all the points comprising a low-resolution version of the data and then points that progressively increase the amount of detail. In addition, parallel architecture and processing could ease the burden of calculations necessary to create the animation sequences on the fly.

The method of Animation of Segmented Components discussed in Section 3.1 was found to depict successfully the existence, locations, and shapes of patterns embedded in the data. The change in the range of the color table together with the change in the range of values of the displayed data increases the resolution of the displayed data values and helps to better perceive the structures. This point was demonstrated by keeping the range of the color table constant during animation (data not shown).

Using this method of Animation of Segmented Components, larger changes are occurring, during the animation run, in objects with fuzzy than with sharper boundaries. This fact, illustrated in figure 3, improves the visibility of fuzzy structures.

The maximal and minimal values of the data displayed are chosen depending on the range of values considered to be interesting in the study. However, if the upper value is chosen to change during the animation process keeping the lower value constant, it will result in expanding and shrinking holes that might distract viewer’s attention. A suitable choice of background color can reduce this effect.

The choice of color scale affects the perceived results. A continuous color scale is preferable to a discrete one, since the latter could create artifactual boundaries that move during the animation process and will distract the viewers attention.

The method of Animation of Blurred Versions of the Data was found to increase the visibility of the structures embedded in fuzzy data. It is our experience that blurring and sharpening the displayed data using image-processing techniques is more flexible than using subsampling progressively. This method is analogous to what microscopists do sometimes to enhance the visibility of objects, defocusing and refocusing. Similarly, piano tuners sometimes fine tune a string by detuning and retuning.

The method of Correlation of Multiple Data Sets Using Animation is useful in correlating different data sets representing the same spatial area. Objects corresponding to close or the same spatial vicinities could have different shapes in the two data sets. Since motion correspondence is not determined by shape, form, or small details, the visual system might still accommodate correspondence between differently looking objects. This could hold whether the corresponding objects are somewhat separate in space or superimposed on each other (Ullman, 1979; Ramachandran and Anstis, 1986; Gershon, unpublished results).

In conclusion, this approach of creating dynamic changes on the screen could be extremely effective and useful in viewing data, especially low-resolution data.
Figure 3. The effect of an animation of segmented components on the visualization of fuzzy and sharp objects. The figure depicts a cross section through narrow and wide objects in a data set. Since both objects have the same peak values but spread over different areas, the wider object should look fuzzier than the narrow one in a static display. However, during animation of segmented components described in Section 3.1, the boundaries of the fuzzy object travel larger distances than the ones traveled by the boundaries of the narrow object. This property could contribute to a better perception of the fuzzy object during the animation.

These methods could play a significant role in the display of browse products of massive data and information systems. The methods presented in this work rely on the ease with which electronic display devices change their display and on the special properties of motion perception by the human visual system. In this sense, it is another example of the importance of understanding human perception in visualization of data.

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References


