Data Presentation through Natural Scenes

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Abstract: The challenge in developing advanced techniques for data visualization is to display large amounts of data for perceptual consumption. From early maps and graphs to n-dimensional displays and three-dimensional images, graphical data displays are pushing the limits of human understanding. The increasing amount of data for analysis requires more capable displays. We discuss issues in extending visualization techniques to capitalize on the human perceptual system. Drawing on the work from J. J. Gibson and P. Robertson, we introduce the presentation of data via iconographic natural scene generation.

1 Introduction

The challenge in developing advanced techniques for data visualization is to display large amounts of data for perceptual consumption. From early maps and graphs to n-dimensional displays and three-dimensional images, graphical data displays are pushing the limits of human understanding. The increasing amount of data for analysis requires more capable displays. Various issues need to be addressed, such as physical screen limitations and technique scalability, but particularly, human perceptive capabilities.

1.1 Data

What is needed is an understanding of the broad potential for improved visualization and how it might be exploited. In general, visualization attempts to present information in data through the use of graphical displays for perceptual consumption. The data can range from purely physical information such as geographical landmarks (e.g. streets and rivers), to abstract values generated from weather forecasting computer models. They can be obtained as arrays of numbers, sets of photographic images, or collections of textual documents. The displays can vary in size, medium, and technique. Before the advent of computers, maps, books, and graphs produced on physical surfaces such as paper presented important data that could be readily associated with various types of information. Maps, for example, are visualizations that present in a schematic view the physical environment, if of a city, its streets, waterways, and parks. They provide information useful for achieving spatial orientation and for giving spatial directions. Maps provide a way to organize one’s environment that can not be directly fixated in the mind (a form of learning about the larger world beyond our immediate senses.) Visualizations are graphical objects designed for visual stimulation in such a way as to provide perceptual access to information.

1.2 Application

From the well-established layout of newspapers to the creation of mathematical graphs, graphical layouts and images can display quite diverse subject matter. Most of these earlier presentation techniques have well-defined rules of composition resulting from years of application to their specific population focus. Take again for example maps, these have evolved from rough diagrammatic displays, based on the inexact measurements of early mapmakers, to today’s art of cartography, which can provide exact natural and manmade geographical locations and boundaries. Displays of information observed daily are evolving and contain ever-larger numbers of values and dimensions, and exhibit them with greater precision and validity.

1.3 Understanding

The development of visualization techniques depends greatly on understanding how graphics convey information to the perceiver. The perception of a given display is rooted in the observer’s knowledge of the underlying data, expectations of the resulting information, cultural background towards such displays, as well as his
immediate comprehension of the display under consideration. Users of maps understand that these represent the geographical surroundings, provide orientation information, contain symbols of their culture, and display lines and regions of landmarks. An important aspect of visualization understanding is the interpretation by the observer of the displayed graphics. This interpretation results from human perceptions and conceptions of the images and what they mean. The interplay of cultural conditioning and display technique inevitably affect the resulting understanding of the display and the information extracted from the underlying data.

1.4 Perception

As with any type of graphical display, visualization methods emphasize the use of the human visual system. More specifically, the human perceptual system plays a major role in the understanding and extraction of information presented visually in the physical world. The evolution of visualization techniques attempts to refine the presentation approach such that the final display will be visually easy to comprehend. The degree of comprehension a specific visualization technique can offer is related to the perceptual mechanisms that the display stimulates. Consequently, it is essential that the capabilities of the human perceptual system be understood in order to enhance visualization applications. The inevitable goal of visualizations is the presentation of data information through displays designed specifically for the human perceptual system.

2 Visualization Techniques

Visualizations have existed for hundreds of years and will remain an invaluable tool for understanding future data sets. Maps are well known for their display of geographical data as mentioned previously. Likewise, the use of graphs in mathematics is a standard method for presenting solutions to specific functions. Graphs are generally considered the first form of scientific visualization displaying numerical values of n-dimensional data sources. Modern techniques have extended graphs to present more data points in higher dimensional spaces, including scatter plot matrices and iconographic displays.

2.1 Graphs

In contrast to the physically related data portrayed in maps, mathematical graphs present the abstract values of functions and sets. As a means to understand functions, graphs generally present observers with a two-dimensional display of specific solutions to functions. These functions, either discrete or continuous, define curves, surfaces, or volumes, in an n-dimensional space that are be presented as two-dimensional projections in a graph. Scatter plots, a subset of graphs, typically display members of mathematical sets rather than function solutions. Scatter plots are commonly seen in statistics displays that present sampled data in order to deduce a generalizing function. Graphs have not evolved quite like maps, but rather changed mediums, from rough hand-drawn sketches to close approximations generated by computers.

2.2 Scatter Plot Matrices and Glyphs

In the use of graphs, and specifically scatter plots, it is important to keep in mind two issues. First, these visualizations represent projections of the data from an n-dimensional space to a two-dimensional display plane. Consequently, spatial relationships must be judged with care. In an attempt to side step this problem, the scatter plot matrix was introduced. This new technique presents a matrix of scatter plots pairing each dimension with all other dimensions thus displaying all two-dimensional projections in one visualization. However, the matrix solution requires the presentation of each original scatter plot as a miniature window and thus results in a loss of detail. Second, as an attempt to present more dimensions in a single scatter plot the individual case points could be presented as glyphs. Glyphs are representational objects for case occurrences defined by various attributes that are data driven. Each attribute of a glyph would ideally present one extra dimension for the data set and change individual instances by color, shape, or size. Though very useful, each glyph now requires more display space per sample point and hence limits the number of cases that can drawn while still providing a clear image.

2.3 Iconographic Displays

Glyphs represent an early attempt at displaying data based on the basic perceptual capabilities of humans: object discrimination and matching. As mentioned above, each glyph is an individual object with data driven
characteristics, such as shape, size, color, etc. An observer obtains information about the data by understanding each sample glyph by its identifying properties. As the number of samples increases, these glyphs must be displayed on smaller scales, consequently limiting the ease of individual identification and differentiation. Eventually the glyphs start to overlap each other and appear as textured regions. Called iconographic displays, these textural visualizations present another perceptual capability, the extraction and identification of patterns in textural fields. The size and overlap of icons provides the display of larger data sets while keeping the same visual stimulation. Such icons have ranged from two-dimensional stick and color icons to three-dimensional icons. Hence, the current visualization techniques are attempting to use the preattentive perceptual mechanisms of the human visual system [7].

2.4 Current Limitations

For all of these modern visualization techniques, the physical display devices and the human perception system are areas of concern. Containing only a few million pixel positions, the output devices force visualization developers to consider both the size of the input data set and the number of dimensions possibly presented. To maximize the number of samples a technique could display, the output requires one sample per pixel. The other option is to decrease the number of case samples and increase the number of presented dimensions. Here a display could use some graphics techniques mentioned for scatter plots such as color, shape, size, line weight, etc.; however, as the method becomes more complex, the available output space is reduced, yielding room for fewer samples in the final display.

Similarly, the human perceptual system easily accommodates large quantities of data if involving only a few dimensions, but perceptual saturation is probably greatly reduced with current displays as dimensionality is raised further. The scatter plot technique is a prime example where an increase in graphical styles to present more dimensions tends to create more perceptual confusion than visual clarity. Hence the development of iconographic images, which can present data of high dimension in a textural presentation to exploit other perceptual channels. It is the potential for reaching these additional channels that is of great concern here.

3 Human Perception

Designers of visualization techniques need to understand the human perceptual system as much as possible to get the most out of human perceptive capabilities. Early visualization tools, such as maps and graphs, evolved slowly over time by trial and error. Future techniques do not have the luxury of such an uncertain path and thus require formal knowledge of human perception with which to proceed in a systematic and predictable approach.

3.1 Ecological Psychology

In our approach to scientific data visualization, we rely on principles of ecological psychology [4]. This approach assumes that the perceptual apparatus has been designed through evolution to respond automatically to natural scenes with computations that yield valid impressions of their ecological meanings. These computations occur automatically and afford the observer the opportunity to react to the environment rapidly without "thinking" – without having to await the results of slower consciously controlled interpretations. Implicit in this ecological view of perception is not only that the interpretations can be rapid as well as true to the ecological meanings of the scene, but also that they can effect very high capacity and comprehensive analyses of the scene because they are not limited by the narrow confines of conscious attention and short term memory. Also, they can presumably be very flexibly adjusted by the behavioral demands of the situation to analyze different aspects and levels of the information in the scene.

The relevance to scientific data visualization of this ecological view of perception is that whatever these perceptual processes are that can be triggered by natural scenes, they ought to be triggered to the same potentially useful effect by data displays designed to mimic natural scenes. Thus, if we can understand the rules whereby various parameters of real substances, real objects and real scenes control the appearance of natural scenes and then map data onto those parameters, we can harness these natural perceptual processes to explore and analyze scientific data. Our artificial display will trigger comprehensive natural computations of the data. The results of these computations will, of course, be impressions of various potential ecological meanings of the display. But, these impressions will not be arbitrary. They will be the results of lawful computations related to underlying structures in the data. The challenge, of course, is then to assist the observer in expressing these impressions in forms that allow the underlying structures to be localized, identified and measured in some useful form. The general approach would
be to have the observer point out perceptually discernible structures and to control numerical computations that bring out the numerical and statistical meanings.

By having the observer adopt different ecological perspectives of the display – i.e., "imagine now that you will have to crawl through this apparent field of shrubs, where would you encounter the most resistance or abrasion?", "if this were a carpet-like surface, how would it feel if you rubbed your hand over it?" Different vicarious physical interactions would presumably trigger different ecologically relevant scene analyses and, in turn, different perceptual computations of the same underlying data. Clearly, much has to be done to design the displays and to support observers in conducting their analyses and in bringing out the structures they detect.

4 Natural Scenes

It is inevitable that future visualization techniques will present data in more realistic displays, harnessing the complete power of the human perceptual system [10]. Current visualization methods only involve a limited selection of perceptual attributes due to the display’s abstract and stylistic presentation of visual objects. Necessarily, graphical data presentation techniques will require icons to appear more physically real [6]. Our perceptual systems were designed specifically for the surrounding external environment, not abstract objects and images [1][2][3][4][5]. It is extremely rare to find objects in the world that resemble ideal bodies, perfect geometrical shapes. Thus, the display of data should utilize shapes that are familiar in nature, for which the visual system has evolved. It is also important that the generated objects visually convey physical properties, such as how trees and grass bend in the presence of wind. From static surfaces to dynamic objects, natural scenes provide the means to present data in a systematic way that is visually perceptive.

4.1 Display Generation

The example natural scene images we present were generated using an experimental iconic visualization system. In this system, icons are modeled using Lindenmayer systems (L-systems) [7][8], in which the grammar represents the uninstantiated, generic icon, and a grammar derivation generates a specific, instantiated icon. To produce a visualization, a grammar derivation is performed with respect to each record, and certain elements of the derived string are interpreted graphically to create an image of the icon.

There are many varieties of L-systems. Our visualization system employs a variant of the Open L-systems grammars [9], because Open L-systems provide a mechanism for communicating between the grammar and external objects (in our case, the visualization system). The selection of which L-system type to use is not paramount, as long as the L-system can be extended to allow communication between the grammar and the visualization system. The icon grammars employ simple graphical commands for orienting, moving, and drawing line segments in two- or three-dimensional space, as well as setting the current line color. The resulting images are rendered with an OpenGL library.

![Figure 1](image) Configuration of the river icon.

The images created for this paper are composed of several types of icons: a river icon, grass icon, and three types of tree icons. The configuration of the river icon is shown in Figure 1. The river icon is the simplest icon, consisting of a line parallel to the X-Z plane. The icon has two data driven attributes, line color and azimuth. The
azimuth is restricted to range between 0 and 180 degrees. This icon forms flat textures that might be appropriate for representing bodies of water.

![Diagram](image)

**Figure 2** Configuration of the grass icon.

The configuration of the grass icon is shown in Figure 2. The grass icon is composed of two limbs, each having four data driven attributes: azimuth, elevation, length, and color. Azimuth controls the orientation of the limbs in the X-Z plane, while elevation controls the orientation of the limbs in the X-Y plane. The body limb's elevation is limited to range between 0 and 90 degrees, while the other limb utilizes the full elevation range of -90 to 90 degrees. The azimuth of both limbs ranges from 0 to 360 degrees. This icon attempts to form grass-like textures.

![Diagram](image)

**Figure 3** Palm tree icon.

![Diagram](image)

**Figure 4** Spruce tree icon.
The tree icons simulate different types of trees, but have three common data driven attributes: their age (iteration level), branch-size, and color. Figures 3, 4 and 5 demonstrate the palm icon, spruce icon, and maple icon, respectively, under varying data conditions. The age attribute controls the number of times a tree grammar is iterated. Each iteration increases the complexity of the resulting icon by causing the tree to "grow" additional branches. Figures 3, 4 and 5, show a sequence of iterations to each grammar, with the iteration levels increasing from (a) to (c). The lengths of the individual line segments that compose the tree are proportional to the branch-size attribute. In Figures 3, 4 and 5, the branch-size attribute is shown increasing from (a) to (c). The combined effect of the age and branch-size attributes allows the icons to simulate many varieties of trees, such as small-old trees or tall-young trees.

4.2 Results
We apply the natural scenes technique to visualization of a Great Lakes database. This database consists of four gray-scale satellite images, 100 pixels in width and height, of the Great Lakes region, as shown in Figure 7. The natural scene created in this example utilizes three icon types, the river icon, the grass icon, and the maple tree icon.

Figure 7b is used by the grammar to segment the image into the different icon types. The grammar examines the normalized data value of Figure 7b for a given record, and performs the following classification:

<table>
<thead>
<tr>
<th>Data Value</th>
<th>Icon Type</th>
</tr>
</thead>
<tbody>
<tr>
<td>Value &lt; 0.2</td>
<td>River</td>
</tr>
<tr>
<td>0.2 ≤ Value &lt; 0.6</td>
<td>Grass</td>
</tr>
<tr>
<td>Value ≥ 0.6</td>
<td>Maple Tree</td>
</tr>
</tbody>
</table>

Based on the value of the classifier parameter, the grammar selects a production corresponding to the appropriate icon type. We did not have data that could be used to provide segmentation values, so the classification values were selected subjectively.

The river icon's azimuth attribute is mapped to Figure 7c, while its color attribute is mapped to Figure 7d. The grass icon's body limb has its azimuth attribute mapped to Figure 7a, its elevation mapped to Figure 7b, its length mapped to Figure 7c, and its color mapped to Figure 7d. The second limb has its azimuth attribute mapped to Figure 7d, its elevation mapped to Figure 7a, its length mapped to Figure 7b, and its color mapped to Figure 7c. The tree icon uses only two attributes in this example, branch-size and color. The age (iteration level) is the same for all of the tree icons. The branch-size attribute is mapped to Figure 7a, while the color is mapped to Figure 7b.

Figure 6 shows one view of the resulting visualization. In these natural scene examples, the output intensity values have been inverted, so that darker colors represent higher values.

The brain MRI source images are shown in Figure 8.

In the next example we apply the natural scenes technique to the visualization of a medical image database. This database, shown in Figure 8a-f consists of six gray-scale magnetic resonance images, 256 pixels in width and height, of a human brain. The natural scene created in this example employs the five icon types discussed in the paper, the river icon, the grass icon, and the three tree icons. Figure 8a is used by the grammar to segment the image into different icon types. The normalized data values are examined and the data is classified according to the following table:

<table>
<thead>
<tr>
<th>Data Value</th>
<th>Icon Type</th>
</tr>
</thead>
<tbody>
<tr>
<td>Value &lt; 0.28</td>
<td>River</td>
</tr>
<tr>
<td>0.28 ≤ Value &lt; 0.4</td>
<td>Grass</td>
</tr>
<tr>
<td>0.4 ≤ Value &lt; 0.55</td>
<td>Palm</td>
</tr>
<tr>
<td>0.55 ≤ Value &lt; 0.9</td>
<td>Spruce</td>
</tr>
<tr>
<td>Value ≥ 0.9</td>
<td>Maple</td>
</tr>
</tbody>
</table>

As before, the segmentation values were arbitrarily selected for this example. The river icon's azimuth attribute is mapped to Figure 8d, and the color attribute is mapped to Figure 8f. The grass icon's body limb has its azimuth attribute mapped to Figure 8d, its elevation mapped to Figure 8a, its length mapped to a Figure 8f, and its color mapped to Figure 8b. The second limb has its azimuth attribute mapped to Figure 8b, its elevation mapped to Figure 8c, its length mapped to Figure 8e, and its color mapped to Figure 8a. The tree icons all use the same mapping, and in this example all three attributes are used. The age attribute is mapped to Figure 8f, the branch-size attribute is mapped to Figure 8e, and the color attribute is mapped to Figure 8c.

Figure 10 shows one view of the resulting visualization. By increasing the spacing between the icons and altering the viewpoint, a close up view can be created to allow the individual icons to emerge, as seen in Figure 9.
5 Conclusion

The initial results from our work appear promising, but further work is clearly needed. There are several scaling and resolution issues that need to be resolved. The icons types used in this paper were not particularly realistic looking. Improved icon types that simulate natural objects more accurately could have a dramatic impact on the resulting visualizations. Further, this work needs to be applied to the visualization of non-physically based databases, which may harbor greater potential for improved understanding than imagery databases.
Visualization techniques are rapidly changing to accommodate larger and more complex data sets. Current techniques attempt to use some of the known perceptual capabilities of humans, such as scene segmentation and object identification. Future presentation methods should capitalize on the human perceptual system, which is rooted in the principles of ecological psychology. The human perception systems have evolved over time from the surrounding environment for optimum perceptual consumption of information. By harnessing these capabilities, it should be possible to present more data in higher dimensional spaces than standard techniques.

References