VISUALIZATION OF ECOLOGICAL AND ENVIRONMENTAL DATA

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Abstract. Scientific visualization encompasses a wide range of image generation methods, from open-ended, general-purpose software packages (e.g., AVS™, IBM Data Explorer™), to domain-specific geographic information systems (GIS). This paper provides a synoptic view of what it takes to develop meaningful, quantitatively reliable and presentable thematic images appropriate to the unique requirements of ecologists and their environmental and ecological data. It presents an overview of processing methods and resource requirements, and is intended to enable individual researchers to anticipate and plan for visualizing their research data.

INTRODUCTION

Ecological and environmental data have a variety of distinctive features making them both valuable and challenging to visualize (Helly et al. 1996, Gross et al. 1995). Chief among these is the fact that these data are irregularly and sparsely distributed in space and time. This is due to the difficulties inherent in field sampling large geographical areas over long periods of time at frequent intervals and numerous locations. These limitations are amplified by the cost associated with related laboratory analyses, and the difficulty in replicating experimental units. The development of useful quantitative images in a meaningful context is made more challenging by the need to correlate and integrate survey data with ancillary data covering widely ranging spatial and temporal measurement scales. The tools to accomplish this fall into the category of visualization and, more specifically, scientific visualization software, as a consequence of the quantitative nature of the resultant images.

To represent the range and diversity of ecological and environmental data, this paper presents three visualization projects undertaken in recent years at the San Diego Supercomputer Center (SDSC). These projects are distinguished from each other by the kind of data used to produce the images. The reason for choosing these three examples is that they span the range of strictly observational field data to strictly computer-generated data. The first example (Plate 1), bird abundance data, represents data that are sampled irregularly in space and time and contain missing values (San Diego Bay Project, *http://sdbay.sdsc.edu*). The second example (Plate 2), solar radiation data, possesses aspects of each of the other two since it contains data that are sampled regularly in time, but irregularly in space (The Solar and Meteorological Surface Observational Network (SAMSON), *http://www4.ncdc.noaa.gov/cgi-win/wwcgi.dll?WWNolos ~Product~CD-006*). The third example (Plate 3), landscape erosion, is typical of data sampled regularly in space and time with no missing values. By regular we mean that data points occur in a systematic pattern. This may be realized as a rectilinear pattern like a rectangular grid (Plate 4), or a curvilinear pattern like an ellipse. A description of the production of each image is followed by a discussion of methods for obtaining presentable hardcopy and softcopy output and the resource requirements.

THE PROBLEM OF IRREGULAR DATA

The principal problem with irregular data in visualization is the need to interpolate it onto a regular grid so that it can be displayed on a two-, or sometimes three-dimensional output device. While there are many methods for doing this, they are generally cryptic and require considerable knowledge of the underlying numerical methods to use them effectively. Recently, some software systems have been offered which greatly reduce the burden on the novice programmer (Fortner Software, *http://www.fortner.com/*) and there are extensive compilations of public domain software for the more experienced (Netlib Repository, *http://www.netlib.org*). Ultimately, numerical values must be mapped to pixel values on a screen or hardcopy. Significant distortions and inaccuracies can be inadvertently introduced into images by inappropriate use of interpolation techniques. It is important to recognize that steps involving interpolation are not always obvious to the uninitiated. Typically, some interpolation occurs explicitly under user control, however, additional interpolation may also occur implicitly within the visualization tools during the definition of object geometries, and especially during the 'rendering' process. Consider, for example, the common problem of aliasing or 'stair-stepping'. These are common interpolation artifacts interfering with the production of continuous-tone images. Proper use of visualization methods requires an understanding of how and where interpolation is used and an understanding of the type and limitations of the sampling methods used to collect the data being interpolated. Both types of knowledge are needed to evaluate the effect of interpolation on data presentation.

THE NEED FOR EXPLICIT DEFINITION OF SCENE COMPOSITION

Modern visualization packages tend to organize themselves around the type of object to render and the type of data structure needed to perform the rendering. For example, an isosurface will generally require a different type of underlying data representation, or data model, than will a volume. Most of the time spent pre-processing data for use in visualization is associated with 'shaping' the data for a particular data model. Therefore, to minimize wasted effort and false starts, it is useful to clearly define the information content of the desired scene. One should consider, for example:

- Are you interested in developing maps or displaying process dynamics? Maps are often multivariate and can be approached using scientific visualization tools or GIS (geographic information systems). Currently, process dynamics are best visualized using scientific visualization tools since they generally provide greater control over the way in which data objects are formulated and rendered, and provide functions to semi-automatically generate a sequence of related images required for an animation.

- What are you trying to show; what is your theme? Multiple themes generally require multiple color maps and legends. The depiction of discrete or categorical data will usually have different requirements than will continuous data. If you are using a map as a background it will be important to consider issues such as vertical exaggeration of relief, viewpoints, direction of lighting, and scale and resolution of thematic data relative to the underlying 'basemap'.

- Do you want to be able to measure things from your image or use it simply for illustration? Quantitatively comparing thematic values across images requires consideration of issues such as controlling data ranges for color maps between images to ensure comparability as well as image size (i.e., number of pixels in rows and columns). For maps, some projections are better suited for linear and areal measurements than others (e.g., universal transverse mercator

(UTM)), and some projections are better suited for some parts of the world than others (Alpha et al. 1982, Bugayevskiy and Snyder 1995, Robinson and Snyder 1991, Snyder 1987).

- Do you want to depict a time series or a cumulative result? Time series animations usually require some type of clock indicator to inform the viewer of the location of any given scene in the series. Cumulative results may require encoding the displayed thematic data in both space and time.

GENERALIZED PRODUCTION STEPS

Regardless of the specific research goals, there are three major steps in the production of images using scientific data: acquisition, transformation (or pre-processing), and visualization. These steps are largely defined by the interfaces and processing required to obtain data from multiple sources and convert them to a suitable form consistent with common spatial, temporal and quantitative scales and the input requirements of the visualization data models.

1. The time spent acquiring, transforming and integrating data for a given scene can grow exponentially as the number of data files increases. The acquisition of basemap data (e.g., Plate 2), can be accomplished through the World Wide Web for certain types of publicly available data such as the 1-degree quad data available from the USGS web site (National Mapping Information, *http://mapping.usgs.gov/*). A great deal of other important data such as precipitation and winds can be very difficult to find for any given location due to the sparseness of the sampling stations and difficulties involved in finding the creators and maintainers of the data. The advent of digital libraries and data repositories will help to reduce some of these difficulties but these are still in developmental stages (CEED: Caveat Emptor Ecological Data Repository, *http://ecodata.sdsc.edu*; ACM Digital Library, *http://www.acm.org/dl/*).

2. Transformation of the raw data into a form suitable for ingestion by the visualization software is an *ad hoc* process involving the use of ASCII editors (e.g., vi or emacs) and general-purpose data processing software (e.g., SAS™ (Statistical Analysis System, *http://www.sas.com*), S-Plus™ (S-Plus, *http://www.mathsoft.com*)). Much of this effort is spent in quality assurance/quality control to determine data ranges, sorting, and statistical summarization into regular spatial and temporal patterns. Finally, the data are written out to files to be used for input by the visualization software.

3. How visualization is accomplished depends largely on the software and hardware available since the cost of these tools is usually quite high. Most researchers are required to make do with the resources at hand. At the time of this writing, modern visualization methods are generally executed on UNIX workstations with significant processor and storage capabilities. Visualization is highly memory-intensive since the object geometries must be largely held in memory as the image is rendered. At present, the dominant visualization tools at SDSC are IBM Data Explorer™ (IBM Data Explorer, *http://www-i.almaden.ibm.com/dx/*) and AVS™ (Advanced Visual Systems, *http://www.avs.com/*) for scientific applications and ARCINFO™ (ARCInfo, *http://www.esri.com*) for GIS applications. There are many other tools available with their respective pros and cons, and opinions on these will vary widely.

EXAMPLE 1: MAP OF BIRD ABUNDANCE FROM FIELD SURVEY DATA

The basemap in Plate 1 is composed of bathymetry data on a rectangular grid with 50-meter spacing originally in state-plane coordinates. The coastline is described by vector data stored as ordered pairs of state-plane coordinates; both provided by US Navy. The geographic (or geodetic) coordinates and names of the sample stations were taken from reports produced by the Unified Port District of San Diego, as were the thematic bird abundance data. These data were then georeferenced in the following way. The gridded bathymetry, and non-gridded coastline data were converted to geographic coordinates using SAS™. Station names were plotted on a navigational chart to obtain their latitude and longitude pairs. The thematic bird abundance data were merged with station names. These were organized into three separate data streams from four individual flat, ASCII input files. These georeferenced data were then converted to a UTM projection to preserve the spatial accuracy of the map. Map projections were accomplished using the GCTP™ (General Cartographic Transformation Package) available from the USGS (National Mapping Information, *http://mapping.usgs.gov/*). The processing flow within IBM Data Explorer™ is shown in Plate 5.

Special consideration was given to the problem of color map assignment. These must be chosen such that the bathymetry data do not obscure the thematic data. The coastline was included to sharpen the land-sea boundary. The opaque circles for the abundance data were used to mark station locations as well as to emphasize the discrete nature of the observations. The translucent squares were used to emphasize continuity of habitat while emphasizing the interpolation used to obtain estimate it. Interpolation was accomplished by regridding the abundance data using a nearest-neighbor method in which the radial distance to neighbors was explicitly controlled. Regridding is a colloquialism for the more generic term of resampling used commonly in remote sensing. Detailed discussions of this and related topics can be found in *Remote Sensing and Image Interpretation* (Lillesand 1989). A plan view was chosen since the area depicted is relatively small; only a few kilometers on a side. The image was finally written out as a tiff image file.

EXAMPLE 2: GROWING SEASON DYNAMICS ON A MAP

The basemap for the images in Figures 2 and 6 was developed from USGS 1-degree DEM (Digital Elevation Model) data with the thematic solar radiation data taken from a NOAA CD-ROM [The Solar and Meteorological Surface Observational Network (SAMSON), *http://www4.ncdc.noaa.gov/cgi-win/wwcgi.dll?WWNolos ~Product~CD-006*]. The radiation data were spatially distributed on an irregular spacing at the county level for 20 geographical locations. These data were then combined into regional data set using SAS. This combining of county data into a regional data file was particularly challenging due to the large space requirements. Each county file was 33 megabytes in size due to both the number of observations and the large number of variables in each county file. These data were combined by first dropping all extraneous parameters before merging the daily latitude, longitude, and radiation values for monthly averaging.

The resulting data were converted to a common UTM (NAD83) projection after resolving a spatial registration problem resulting from the use of NAD27 for the DEM and NAD83 for the county stations. As in the first example, the data were converted to flat ASCII input files for input to IBM Data Explorer. The color map assignment was chosen to ensure an intuitive understanding of high versus low radiation values. The images (Plate 6) are not precisely comparable because the mapping of color to data values is not constant between the images. The elevation values were scaled upward by approximately 150% to emphasize vertical relief and provide convenient landmarks without imposing a grid that would interfere with the continuity of the animation.

EXAMPLE 3: LANDSCAPE EROSION DYNAMICS

Since the data in Plate 3 were all computer-generated for five dimensions (x, y, z, time, water-depth) no basemap was required. Three separate model runs were done, each with one file per time step (126, 312 and 96 files; each approximately 1 megabyte in size) and different values for model parameters resulting in different rates of erosion and topography. Similarly, georeferencing and map projections were not required. SAS was used to produce both input data files from the raw data as well as the auxiliary files needed to control the semi-automated generation of such a large number of image frames.

Color maps were chosen to emphasize dry versus wet and to aid in the perception of ridges versus valleys. The view was assigned to emphasize valleys versus ridges and to resolve figure-ground perception difference between two of the investigators. A particularly thorny problem emerged in that as erosion progressed from frame to frame, an obscure parameter in the software was causing the image to be rescaled, which in turn caused the scene to translate vertically on the screen as time progressed due to misregistration between frames. The logarithm of water-depth was chosen to accommodate a range of water depth values of approximately 14 orders of magnitude. Each image frame was successively written to the file system for importing into the video production process used for the animation.

IMAGE OUTPUT

Modern image processing methods have evolved to the point where numerous image file formats can be inter-converted (San Diego Supercomputer Center Image Tools. San Diego Supercomputer Center, (Available via anonymous ftp from ftp.sdsc.edu (132.249.20.22), 1998)). However, there are important differences within image file standards that can be quite puzzling and problematic. There is still the fundamental difference between raster (e.g., tiff, gif, jpg, png) and non-raster (e.g., postscript, hpgl) formats which typically make it possible to convert from raster to non-raster formats effectively, but not routinely in the other direction. As a rule-of–thumb, it is generally safe to rely on the uncompressed, RGB tiff file format as your default choice. There is also a CMYK (i.e., Cyan-Magenta-Yellow-blacK) tiff format used chiefly for offset printing. From this type of image file virtually any desired hardcopy output type can be obtained. This will also be the largest in size so it is sometimes awkward to move it around and process it. At present the second choice is generally jpg which is, however, a compressed format. This is acceptable for many applications, but does not generally contain all of the original image information since it is a 'lossy' compression method. This means that it loses bits through an encoding scheme to save space. There are also 'loss-less' compression methods. There are many graphics service bureaus that can provide hardcopy output as 35mm slides or other professional quality output media beyond what the commonly available printers can provide. Animation file formats are also semi-standardized on MPEG and AVI formats.

SUMMARY

In this paper, examples of visualizing ecological and environmental data have been presented. Each represents an approach to developing meaningful, quantitatively reliable and presentable thematic images. Moderately technical descriptions of processing methods and resource requirements, and information necessary to *plan* data visualizations were provided. Detailed implementation mechanics and, perhaps most significantly, problems associated with the introduction and propagation of map errors were not discussed but can be further investigated in *Environmental Modeling with GIS* (Goodchild 1993).

LITERATURE CITED

Alpha, T.R. and J.P. Snyder. 1982. The properties and uses of selected map projections. U.S. Geological Survey, Reston, VA.

Bugayevskiy, L.M. and J.P. Snyder. 1995. Map projections: a reference manual. Taylor & Francis, London, UK.

Goodchild, M. 1993. Environmental Modeling with GIS. Oxford University Press, New York, NY.

Gross, K.L., C.E. Pake, E. Allen, C. Bledsoe, R. Colwell, P. Dayton, M. Dethier, J. Helly, R. Holt, N. Morin, W. Michener, S.T.A. Pickett, and S. Stafford. 1995. Final report of the Ecological Society of America Committee on the future of long-term ecological data (FLED). Volume I: Text of the report. (*http://www.sdsc.edu/~ESA/FLED/FLED.html*).

Helly, J., S. Levin, W.K. Michener, F. Davis and T. Case. 1996. The State of Computational Ecology. San Diego Supercomputer Center, San Diego, CA.

Lillesand, T.M. 1989. Remote Sensing and Image Interpretation. John Wiley and Sons, New York, NY.

Robinson, A.H. and J.P. Snyder. 1991. Matching the map projection to the need. American Congress on Surveying and Mapping, Bethesda, MD.

Snyder, J.P. 1987. Map projections--a working manual. U.S. G.P.O., Washington, DC.

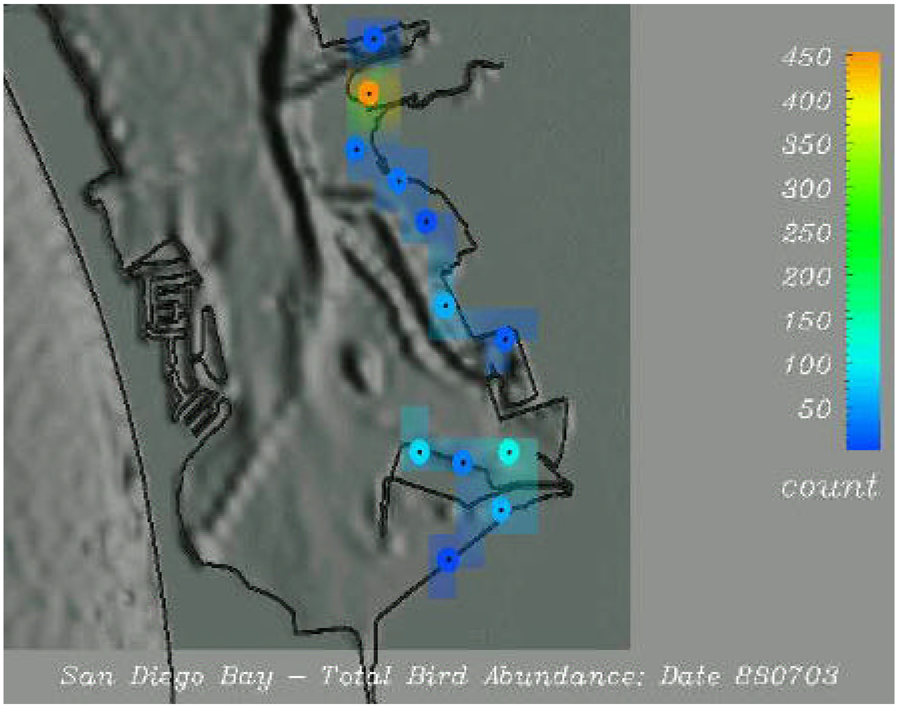

Plate 1. Bird abundance in South San Diego Bay. This image typifies the field survey and map data collected in San Diego Bay. Discrete empirical observations are depicted as opaque circles joined by translucent squares resulting from nearest-neighbor interpolation. T. Todd Elvins and J. Helly produced the image as part of the San Diego Bay Project using IBM Data Explorer™. Data provided by U. S. Navy and the Unified Port District of San Diego; funded by the San Diego Bay Interagency Water Quality Panel.

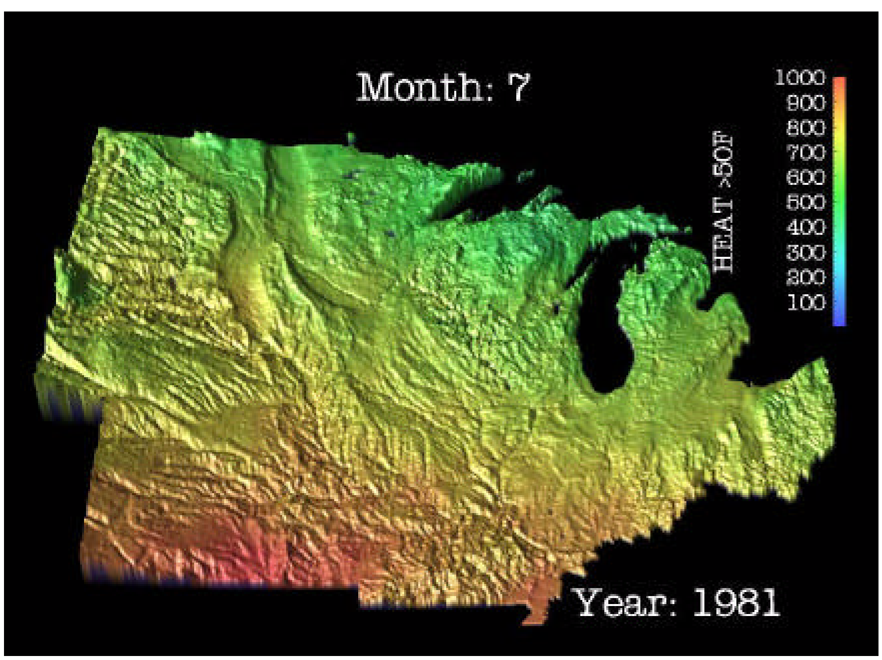

Plate 2. Mean monthly incident solar radiation data collected at the county level of spatial distribution in the Midwest Corn Belt. This is one image from a time-series developed for an animation covering twenty years at monthly time steps. Stuart Gage of Michigan State University, J. Helly and T. Elvins at SDSC produced the image.

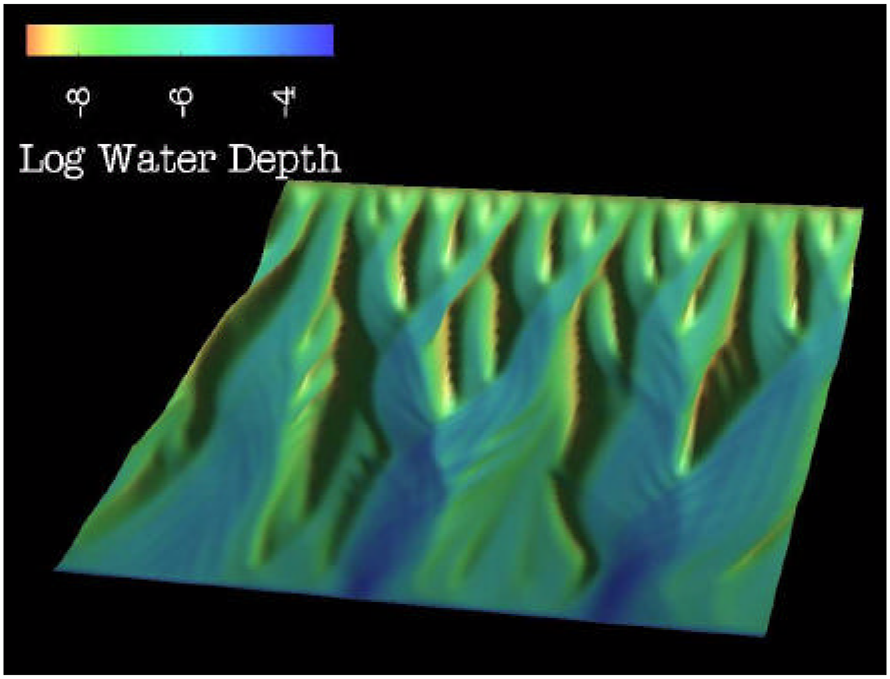

Plate 3. Landscape erosion produced from computer model output. This is one frame from a 312-frame animation used to display the output of a mathematical model describing surface water runoff and associated landscape erosion of a hypothetical ridge. The model was developed by T. Smith and G. Merchant at the University of California, Santa Barbara and the image was produced by J. Helly, T. Elvins and N. Kelly at SDSC.

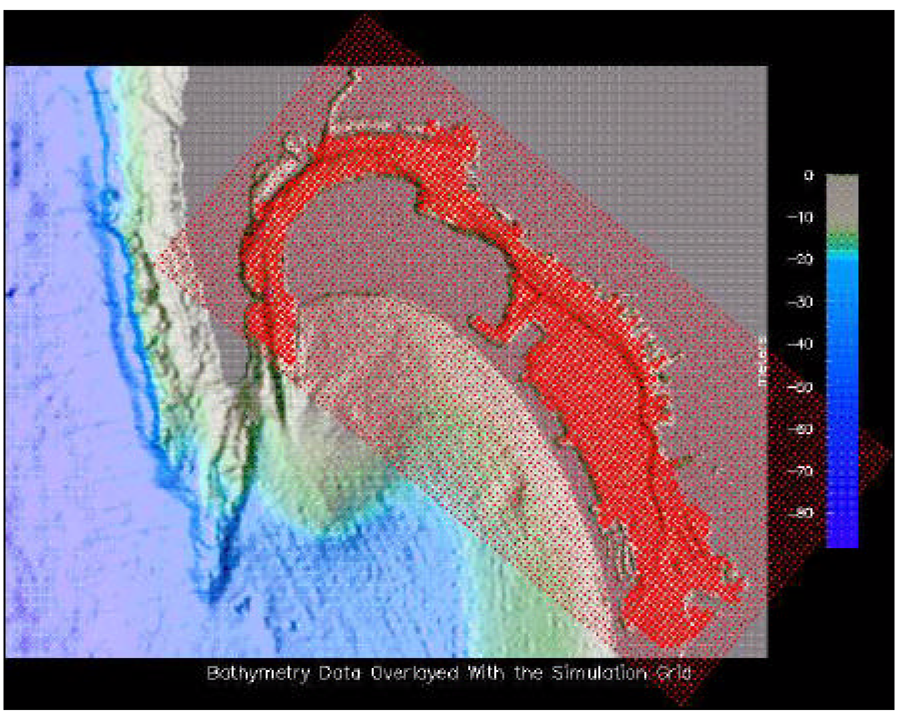

Plate 4. Regular, rectangular grid developed to describe the interior of San Diego Bay for use in hydrodynamic modeling. Image produced by R. Marciano at SDSC.

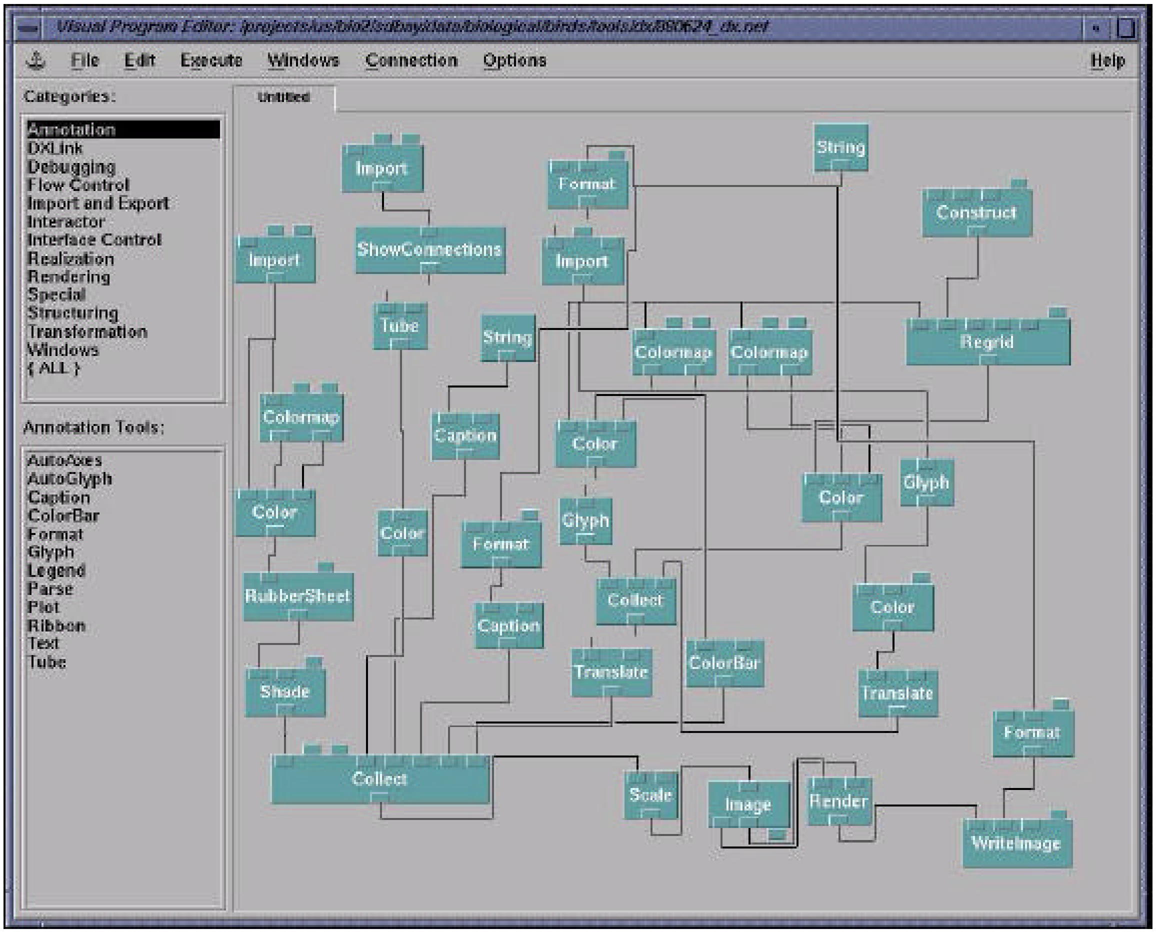

Plate 5. Processing network for bird abundance data using IBM Data Explorer™ (developed by T. Elvins / SDSC).