Three Visual Methods: Envisioning Gradients, Function Extraction, and Tensor Glyphs ©

Class Notes for ESM4714: Scientific Visual Data Analysis and Multimedia

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Introduction

As scientists and engineers we have traditionally used graphs and tables to communicate our ideas and mathematical functions to others in publications and presentations. However graphics is also creatively used to envision complex mathematical ideas and scientific information. Before we construct algebraic functions we imagine its shape graphically, i.e. "it goes like?" -- the idea of linearity is imagined as a straight line, exponential as an increasing sloped line, etc. We are taught in calculus to imagine multi-dimensional functions as shapes where geometric definitions of derivatives are envisioned as iconic patterns of slopes or planes tangent to these functional curved lines or surfaces and integrals of these same functions are envisioned as iconic patterns of areas or volumes. Iconic patterns representing derivatives and integrals enhance our understanding of physical properties that are of no consequence to the mathematician, e.g. the derivative of velocity with respect to time is acceleration and the integral of stress as a function of strain is energy. Using graphics to organize simple and complex ideas is an innate cognitive ability that can be used to envision scientific information and extract complex functions embedded in massive experimental or numerical data sets.

Often scientists and mathematicians (i.e. Gibbs, Maxwell, Einstein, Feynman) reported that before formalizing their ideas into words and symbolic script (equations) their "productive thought" was first to imagine their functional relationship of physical properties as a "combinatory play" of images*. This thought process is an innate visual cognitive-psychical ability that we all experience. Although this experience is not as accurate or reproducible as the final mathematical form, it is however a valuable creative component of how the human mind discovers and presents complex ideas.

These web pages attempt to elaborate on how we can create meaningful psychical images using computer graphic technology that did not exist fifteen years ago. Code fragments are provided with examples on how to create meaningful images. If such images can be created, this cognitive-psychical experience can be shared with others. It is important that applied scientists and enginneers learn how to create these computer images as part of the creative process. Enhanced understanding is realized when graphical models are created together with the development of the mathematical models. In many cases these graphical and mathematical models coincide and enhance our understanding of complex ideas that can not always be explained with either just images or math. Here an attempt is made to combine the use of grapical and mathematical models by developing three general visual methods that work well with massive data sets encountered when working with supercomputer simulations and computer controlled laboratory equipment. Because of recent advances in computer technology, "we are data rich but information poor"**. It is the intent here to create an information rich experience within a mathematical and scientific context.

1. Compress large graphical-tabular data sets into a visual gradient format
   (Cognitive Visual Data Compression),

2. Extract simple relationships from this compressed visual format
   (Pattern Function Extraction),

3. Envision n-th order tensor properties distributed within this compressed format
   (Eigenvalue-Eigenvector Glyphs)

Summary

With these visual methods it is possible to approach the investigation of information embedded in massive data sets in a systematic and rational manner, unlike the chance discoveries so often associated with the serendipitous use of scientific visualization software.

The visual methods created here trade off the more accurate and traditional quantitative techniques for more qualitative but comparative visual techniques. Both techniques are important. These visual methods indeed parallel how we first imagine our functions and mimic our first impressions of possible functional relationships. This "combinatory play" of images does indeed seem to be the "essential feature in productive thought"*. Such an approach is shown here to work well when visualizing the three-dimensional gradient of a scalar function by cognitive visual data compression, extraction of simple algebraic expressions embedded in distributed numbers, and envisioning n-th order tensors and invariance of tensor equations. Through out the development of these methods we have attempted to demonstrate that the mathematical invariance associated with tensor equations can be used to envision the same invariance associated with physical laws, e.g. equlibrium.

Visual methods developed here required exploitation of new graphical features such as rotating voxel volume translucency and planes with color gradients moving through three dimensional space. These methods were developed as an attempt of creating images and animations of "psychical entities" that represent complex physical quantities in insightful new ways for discovery and for presentation to be shared with others. We are still data rich but perhaps a little less information poor.

References

** Albert Einstein in a letter to Jacques Hadamard: "The words or the language, as they are written or spoken, do not seem to play any role in my mechanism of thought. The psychical entities which seem to serve as elements in thought are certain signs and more or less clear images which can be 'voluntarily' reproduced and combined... this combinatory play seems to be the essential feature in productive thought before there is any connection with logical construction in words or other kinds of signs which can be communicated to others".*

*** Professor Michael Vorster in a private conversation with the author Ron Kriz: "We are data rich but information poor". Professor Vorster is the Director of the Constuction Management Program in Civil Engineering at Virginia Tech.*

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http://www.sv.vt.edu/classes/ESM4714/VizMtd.html
