Information Visualization: Challenge for the Humanities

Maureen Stone

Digital archiving creates a vast store of knowledge that can be accessed only through digital tools. Users of this information will need fluency in the tools of digital access, exploration, visualization, analysis, and collaboration. This paper proposes that this fluency represents a new form of literacy, which must become fundamental for humanities scholars.

Tools influence both the creation and the analysis of information. Whether using pen and paper, Microsoft Office, or Web 2.0, scholars base their process, production, and questions on the capabilities their tools offer them. Digital archiving and the interconnectivity of the Web provide new challenges in terms of quantity and quality of information. They create a new medium for presentation as well as a foundation for collaboration that is independent of physical location. Challenges for digital humanities include:

- developing new genres for complex information presentation that can be shared, analyzed, and compared;
- creating a literacy in information analysis and visualization that has the same rigor and richness as current scholarship; and
- expanding classically text-based pedagogy to include simulation, animation, and spatial and geographic representation.

Information in digital form provides unequalled opportunity to combine, distill, present, and share complex ideas. The challenge is to do so in a way that balances complexity with conciseness, and accuracy with essence, that speaks authoritatively, yet inspires exploration and personal insight. This presentation goes beyond illustrated texts organized as pages, or even as Web pages, to include interactive graphical representations based on data.

While literacy in all new media will be crucial for digital scholarship of the future, this paper focuses on *information visualization*, or the creation of graphical representations of data that harness the pattern-recognition skills of the human visual system. The skills that support information visualization include data analysis, visual design, and an understanding of human perception and cognition.

As my specific expertise is color, I will include both the use of color in visualization and the visualization of color in art and history as examples.

What Is Information Visualization?

In computer science research, the term *visualization* describes the field of study that uses interactive graphical tools to explore and present digitally represented data that might be simulated, measured, or archived.

The visualization field split off from computer graphics in the mid-1980s to distinguish graphics rendered from scientific and engineering data from algorithms for creating images of natural scenes, many of which were a blend of scientific, artistic, and technically pragmatic techniques. A further division occurred in the early 1990s to distinguish scientific, or physically based, data from abstract "information visualization," such as financial data, business records, or collections of documents. More recently, the term *visual analytics* was coined to emphasize the role of analysis, especially for extremely large volumes of data. While these distinctions are valuable as a means of providing different foci for publication, for this discussion they are less important than the commonalities.

The primary publishing venues for research in visualization are the IEEE Visualization Conferences and the supporting IEEE publications, *Transactions on Visualization and Computer Graphics*, and *IEEE Computer Graphics and Applications*. Visualization-relevant work can appear, however, in other fields, including computer graphics, human-computer interaction, vision, perception, and digital design, as well as in fields that extensively use visualization, such as cartography and medicine.

Visualization is not unique to the computer science domain. Edward Tufte has written a series of books on the visualization of information that are considered seminal in the field (Tufte 1990, 1997, 2001). Tufte's books are full of fascinating examples of how information can be graphically presented. Tufte also lectures extensively on the topic, forcefully promoting his personal (usually excellent) views on the best way to present information. Tufte's principles of excellence in visualization emphasize conciseness, clarity, and accuracy.

Graphic designers will assert that the graphical presentation of information is their fundamental goal, which they achieve by applying principles basic to art and design—namely, hierarchies of importance, spatial relationships, layering, contrast versus analogy, legibility, and readability. These elements are constructed from careful choices of positioning, shape, color, size, and typography. Cartographers combine these same elements to create exemplars of information display, as do medical illustrators and other specialists.

Historical Visualization

The following historical examples are often cited in talks and classes on visualization.[1]

William Playfare (1758–1823) is credited as the father of graphical methods in statistics. His inventions include the bar chart, the pie chart, and time-series graphs. His goals were political; his focus was government spending.

John Snow (1813–1858) used a dot plot of cholera cases overlaid on a London street map in 1984 to identify and illustrate the source of the contamination.[2]

Charles Minard (1781–1870) created an information graph published in 1869 illustrating Napoleon's disastrous march to Moscow in the Russian campaign of 1812. The flow diagram, plus its paralleling temperature diagram, poignantly illustrates the number of men that died as the temperature dropped to bitter levels.

The Value of Digital Visualization

Digital visualization enables creation and exploration of large collections of data. I would argue, however, that the tools for collection are far more successful to date than are those for exploration. Other than the ability to explore collections of great size, what value does digital visualization provide?

Digital visualization enables interactive exploration. Compare spreadsheets with graphing capabilities (such as Microsoft's Excel) and dynamic maps (such as Google maps) with their static, paper-based versions. I would argue these two examples are probably the most influential forms of digital information visualization yet discovered.

Digital visualization can be combined with simulation to simultaneously explore many potential solutions along with the probabilities and dependencies that influence them. Brain surgeons, for example, can use the data from a CAT scan to explore different approaches to removing a tumor. Such data can also be used to create simulators for training. Stephen Murray at Columbia has used visualization and simulation in his studies of medieval architecture, such as his digital study of Amiens Cathedral.

Digital visualization can be used to monitor changing streams of data. Many major metropolitan areas have Web sites that show traffic flow in real time, such as the one provided by the Washington State Department of Transportation for the Seattle area.

Digital visualization facilitates collaboration. Collaboration, in the sense of sharing, is fundamental to the Web and to digital archiving. The Web site Many Eyes, however, provides a forum for people to upload their data and create visualizations and for other people to comment on them.

---

[1] These three can be found in chapter 1 of Tufte 2001.

[2] See Tufte 1997, 27-39 for a complete description.

The Dark Side of Information Visualization

Some are concerned that digital tools are outrunning literacy in the art and science of graphically presenting information. To put it more bluntly, it is too easy to make pictures that confuse, miscommunicate, or downright lie, either inadvertently or deliberately. Tufte's books show many examples of graphical distortion created by inaccurate uses of scale and perspective, extraneous graphical elements ("chart junk"), and improper presentation of data, such as a graph of costs over time that does not adjust the dollar amounts for inflation (Tufte 2001, 53-78).

Even Tufte is not immune to the risk of misusing visualization. After the Challenger disaster, he analyzed and redesigned the graphs used by Morton-Thiokol engineers to communicate their analysis and concluded that if they had visualized their data more effectively, the risk of launching in cold weather would have been clear. This example is frequently used to illustrate the power of visualization (Tufte 1997, 39-50). I recently uncovered a substantial rebuttal by the engineers, which argues that Tufte did not fully understand the context or the data, and is therefore guilty of falsely making the engineers responsible for the disaster (Robison et al. 2002).

A common criticism of visualization tools, both research and commercial, is that they do not embody basic visual design principles. Colors are too bold, lines are too thick, and fonts are too small, these critics claim. The result is cluttered, ugly, and at worst, misleading. The most recent release of Microsoft Office, with its ubiquitous tools Excel and PowerPoint, touts its refined graphics. But the result is a disaster from a visualization standpoint. Colorful, transparent, rotating 3-D bar charts make good "eye candy" but do not communicate their information about their underlying data any more clearly than simple 2-D graphs. In fact, the former are less effective, because the 3-D perspective distorts the numeric relationships represented by the relative heights of the bars.

Stephen Few is a consultant working in the field of business intelligence whose primary mission is to improve the presentation of business graphics. Few's Web site has many examples of terrible visualizations that he has analyzed and redesigned, most made by commercial systems. His book *Show Me the Numbers* teaches how to effectively communicate with simple charts and graphs (Few 2004). This requires understanding the data, the audience, and the problem being solved. These skills must be taught, and I would argue are important for everyone to learn. (Few has an online Graph Design IQ Test to demonstrate this point.)

People's responses to graphics are not purely intellectual; there is a strong visceral and emotional response, as is well appreciated by those in the advertising and entertainment industries. Pictures made from data are no exception, so both authors and consumers need to be educated about the impact of choices in layout, color, typography, and imagery—all topics more commonly taught in courses in art and design.

Creating effective tools for visualization requires technical skills, visualization skills, and a deep understanding of the problems and tasks critical for a particular domain. One common criticism of visualization research is that it presents techniques that are technically interesting but that do not provide solutions to real problems. This is a classic problem in research tool and system design, where technologists have a vision, based on what is computationally possible, but lack an understanding of what is really needed to solve the problems of their potential users. Potential users ("domain experts"), however, can rarely articulate their needs in a way that directly informs the technological development. Successful collaborations that blend the skills of both are all too rare.

Teaching Information Visualization

Information visualization is traditionally taught as a graduate-level course in computer science departments. The focus is on teaching students already fluent in computer systems and technology how to create innovative information visualization tools. Often, the text is Colin Ware's *Information Visualization: Perception for Design* (2004), plus Tufte's *Envisioning Information*, augmented by selected research papers, such as those found in Card et al. (1999). Students in such classes typically create a project, which serves as a basis for their grade in the course.

More recently, courses have been designed to teach information visualization to undergraduates, often those in disciplines other than computer science. With a colleague, Polle Zellweger, I designed and taught an information visualization course as a fourth-year undergraduate elective in the University of Washington iSchool (Info424 2006, 2007). We based our course on other courses, including one taught by Marti Hearst at the University of California, Berkeley (UC Berkeley CS558), and another taught by Melanie Tory at the University of Victoria. We collected material more widely, especially from Pat Hanrahan (Stanford CS448B), John Stasko (Georgia Tech CS7450), and Tamara Munzner (University of British Columbia CPSC 533C). This year, the course is being taught by iSchool doctoral student Marilyn Ostergren, and it includes more visual design plus collaboration with real projects elsewhere on campus (Info424 2008).

We found it an enormous challenge to select the material to be taught. Is the goal to teach students to design visualizations from basic principles or to help them become fluent in existing tools? Should the course focus exclusively on data visualization, or should it include general topics in visual communication? Is the primary goal to make students aware of the broad range of visualization models and tools, or is it to teach them specific skills, such as how to make good data graphs as taught by Few?

Visualization is a skill that must be practiced for fluency, and that takes time. Art and design schools teach visual communication by making students create, critique, and redesign. They assume a fluency in whatever medium is being used. Digital visualization can be taught the same way, but a single class will have to be focused on specific tools and visual forms. Data visualization requires a good understanding of data, how it is structured, basic data manipulation, and statistical analysis. Interactive visualization requires understanding of basic human-computer interaction techniques and the principles that underlie them.

Our choices are reflected in the class Web sites, but I do not believe we have in any way solved this problem, which is a critical one for iSchools. Our efforts to provide concrete skills focused on data graphics, for which we used Stephen Few's book and taught the students how to use the commercial visualization product from Tableau Software. While important, this is too narrow a focus for visualization literacy in iSchools and the humanities. We also used Tufte's *Envisioning Information* for its rich insights, but that does not provide any exposure to interactive and animated visualization. Over two years, we tried several approaches for including interaction principles and skills, relying heavily on examples found on the Web, but were never entirely satisfied.

Color in Visualization and the Visualization of Color

Color is a key element in visualization. It can be used to label, to quantify, to focus attention, and to contribute to the visceral sense of style. The perception and cognition of color is also important and is strongly linked to its usefulness in visualization, as well as to our overall view of nature and the world. The mechanisms for creating color are fascinating and complex, from the displays in nature to the technology of paints, dyes, film, and digital media.

Like visualization, color can be viewed from scientific, artistic, and technical perspectives. Using color effectively requires insight and practice. This section of the paper discusses color literacy as a subspecialty of visualization literacy.

The Craft of Color: An Example

In *Envisioning Information*, Tufte attributes the excellence of Swiss cartography to "good ideas executed with superb craft." The resulting maps pack an immense amount of information into an elegantly useful visual package. Typically, I would now include an image of such a map as an illustration, but it would not capture the beauty of the original, and at worst, would give a completely incorrect impression of its appearance.

Maps are traditionally designed to be printed on paper, with the specific technique depending on the age of the map. I believe the map Tufte admires was designed to be printed on an offset printing press. An offset press prints in inks of different colors, but with no gradation in the color, in contrast to film or displays. For any given spot, ink is either present or not, with high-frequency patterns called "screens" or "halftones" used to vary the lightness. Offset inks may be any of a wide range of colors, and may be transparent or opaque.

The high-quality printed map that Tufte admires would be produced so that each different color was printed as a separate layer, using as many as a dozen printing plates, each with a different color of ink. The design of the map would take every advantage of this process. Each information layer, whether contour lines, grids, text, or the shading to indicate topography, would be crafted to print beautifully.

A commercial offset printer does not have the luxury of unlimited numbers of plates and inks, but instead uses four standard colors: cyan, magenta, yellow, and black. To reproduce a map in a textbook, for example, requires simulating the original map colors by halftoning and combining the standard four colors. Some of the original colors may not be accurately reproducible, which can change the effectiveness of the color encoding. Halftoning also introduces texture. As a result, symbols that were crisp and legible when printed with a solid ink may become fuzzy and less easy to read. A map designed for a commercial offset press, however, would be crafted to ensure that fine lines and text were printed with dark, sufficiently solid colors, and that all colors used in the color encoding would print reliably and distinctly.

Reproducing Tufte's map on a display introduces the complex color-transformation problems between displays and print, and the relative crudeness of the display resolution. Features smaller than a pixel must either become larger or blurred, resulting in illegible or overly bold contour lines, symbols, and text. Maps designed for displays, however, replace these fine features with the ability to dynamically zoom and label. Colors, too, can be dynamic, adding a new dimension to the color encoding.

In all cases, visual perception constrains the choice of line weights, fonts, and colors. The visual factors that affect the legibility of text, symbols, and fine lines are spatial acuity and luminance contrast. *Spatial acuity* is the ability to focus on and discriminate fine patterns of lines (edges); *contrast* is the difference in perceived lightness (luminance) between a foreground object and its background. The choice of colors for rendering and encoding must consider not only luminance contrast but also the effects of simultaneous contrast and spreading.[3]

What can we learn from this example, other than that it is difficult to reproduce color well? First, it should be clear that designing well with color requires knowledge of the materials used to produce it as well as some practical knowledge of human visual perception. It should also be clear that what makes color aesthetic and effective depends on the technical properties of the medium and the culture and economics that support it. Finally, it serves as a warning about the complexity of archiving color: viewing its digital rendering will not be the same as viewing the original object.

---

3 For more information on color perception, technology, and the difficulties of transferring colors across media, see Stone 2003.

Color Design Guidelines: Do No Harm

Tufte's primary rule for color design is "Do no harm." The complete quote talks both of the power of color in visualization and its ability to confuse, and therefore recommends using color sparingly and only for very specific purposes that he calls "fundamental uses." These uses are "*to label* (color as noun), *to measure* (color as quantity), *to represent or imitate reality* (color as representation), and *to enliven or decorate* (color as beauty)" (Tufte 1990, 81). Consider this map of the area around the Point Reyes National Seashore, designed by the National Park Service. Color is used extensively to label, including the roads (whose different shades of red indicate their relative size), the cities, the land, the water, and the park area.[4] Using blue for water and green for the park is an example of imitating reality, which is typically done in an illustrative rather than a realistic way. The map is designed to read well when reproduced in shades of gray, but the color version is both more aesthetic and effective.

Fig. 1: Region map for Point Reyes.
Courtesy of the US National Park Service.

The following map, taken from the Census Atlas of the United States, uses color to indicate population density. The darker the color, the higher the density, as indicated in the legend. This is an example of color as quantity. This type of color encoding is used extensively in data maps like this one (called a chloropleth map), and also in more abstract information visualizations, such as the color-coded "Map of the Market" presented on the SmartMoney.com Web site.

---

4 Please see the online version of this publication for color renditions of Figures 1 and 2, available at http://www.clir.org/pubs/abstract/pub145abst.html.

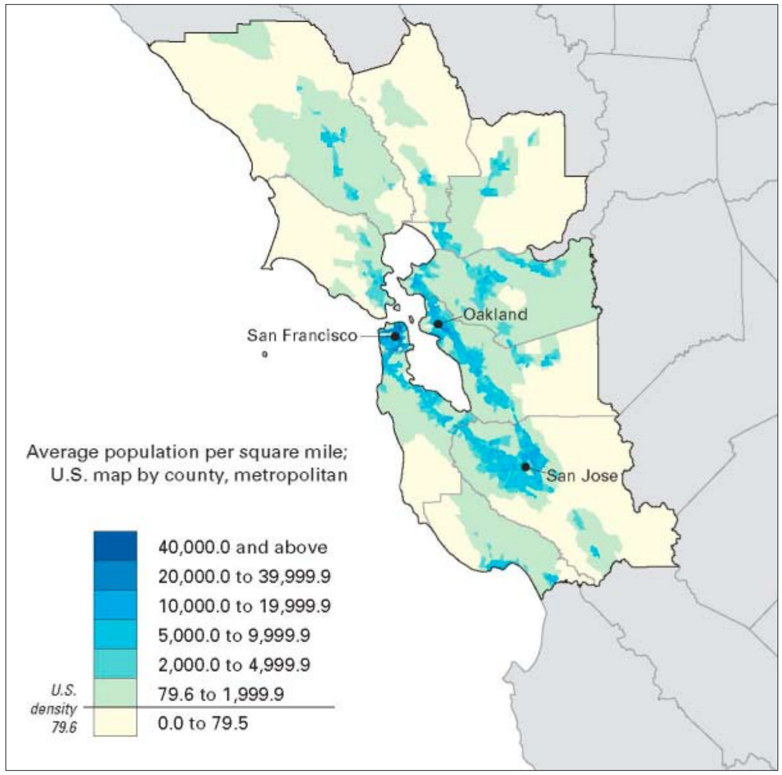

Fig. 2: Population density for the San Francisco Bay area. Courtesy of the U.S. Census Bureau.

Learning how to do excellent visual design takes dedication, skill, and practice. With appropriate tools and guidelines, learning to avoid making awful visualizations may be simpler.

Example: Voting System Guidelines

Under contract with the National Institute of Standards and Technology (NIST), I recently wrote a set of guidelines for the use of color in voting systems (Stone et al. 2008). A primary motivation was to ensure accessibility for individuals with color vision deficiencies, but we were able to create guidelines that should greatly improve the use of color for everyone. The irony is that color use in paper ballots is usually constrained by the economics of printing—white paper, black text, perhaps one other color for labeling. But, given a color digital display in a voting kiosk, developers now have the opportunity to use, and to grossly misuse, color.

Our objective was to create a simple, testable set of rules that would eliminate the gross misuses of color and encourage its proper use. Our first goal was legibility, which is most easily achieved by severely restricting the use of colored text. Our second goal was to avoid the “color chaos” caused by the indiscriminate use of color. For this we required a consistent mapping between color and its function.

Example: Make the Easy Choice the Right One

Tools for creating visualizations have the opportunity to encode good practice in their design. An example is the system created by Tableau Software for data exploration and visualization. Tableau Software is the outgrowth of research at Stanford University on data visualization and analysis. It is run on a workstation that makes it easy to interactively create charts, graphs, and data maps to explore a database of numerical and categorical information. Fundamental to the design of the user interface for this system is the desire to make it easy for the user to create effective, aesthetic visualizations.

I worked with Tableau to design the colors and, equally important, the interfaces used for assigning colors to their data visualizations, which consist of tables, graphs, scatter plots, and bar charts. As well as designing color palettes that were legible and uniquely colored (for labels), or smoothly varying (for quantity), I worked with the developers to design user interfaces that encouraged good use of color.

Most color-selection tools allow users to choose a color point in some color space. The guiding principle for the Tableau user interface, by contrast, is to map a set of colors to data. For labeling, users first select a palette, or set of coordinated colors, that can be applied in one operation to the entire data set. Users can also select individual colors from different palettes, or even customize individual colors using a traditional color tool, but the simplest operation is to accept the default palette, or to choose a similarly well-crafted one. A similar approach was used for the colored ramps used to map colors to data.

My colleagues at Simon Fraser University and I have begun some studies of grids and other visual reference structures that are traditionally designed to be low contrast, yet legible (Bartram and Stone 2007; Stone et al. 2006). Graphic designers can layer information without causing visual clutter by controlling the relative contrast of the data elements. The elements can be designed for a specific set of information and medium, but in digital visualization, both are dynamic. We seek ways to understand and quantify the subtle aspects of visual representation required in dense information displays so that they can be algorithmically manipulated to match human requirements in interactive and dynamic conditions.

Our approach to this problem is not to characterize “ideal” or “best” but to define boundary conditions outside of which the presentation is clearly bad. We reason that the best solution will always depend on context as well as on individual taste. Boundary conditions are likely to have simple rules that can easily be incorporated by engineers and researchers and are less likely to be influenced by individual taste.

Visualizing Color

That colors change when reproduced is not new with digital media. Posters of great artworks provide only an impression of the original work. Nonetheless, such reproductions have value. The important thing is to understand their context and limitations, and then to augment them with additional analysis and information. Even a crude reproduction can answer basic questions about form, layout, and even color and shading. The change in painting style from medieval images of the Madonna (which are flat and feature a wealth of gold leaf), to the paintings of Rubens, with their lush and subtle shading, should be clear in even the most basic of reproductions. A comparison in any depth of thirteenth-century colors with those of Rubens, however, should be approached cautiously and should not depend on pictorial reproductions alone.

In *The Bright Earth*, Philip Ball (2003) persuasively argues that to fully appreciate color in art requires an understanding of both the chemistry and economics of color: the Virgin's blue cloak colored with pigment made from ground lapis lazuli is not only beautiful but expensive, reflecting the status of the patron who commissioned it. In a digital visualization, we may not see the proper colors, but we could link to discussions of historical color, to a spectral analysis of the particular paint, and to a symbolic visualization of the color relationships in the painting.

Art curators and historians know that colors change over time, so that the colors of an "original" as seen today are not the same as they were when the work was new. A dramatic example is the discovery that Greek and Roman statues, whose white purity had been held as an artistic ideal for generations, were originally painted. These theories are supported by surface analysis of the stone as well as by historical references to painted, lifelike statues (Gurewitsch 2008).

To illustrate the effect of the coloring, full-size models have been created and colored with historically accurate paints. Pictures of these reproductions, with their shockingly bright colors, are effective illustrations. Viewing the models themselves, however, will provide a much more accurate impression than any picture, just as viewing Michelangelo's towering statue of David is very different from looking at a picture of it. This is not just a limitation of imaging; it is a fundamental part of perception.

The digital data used to create the models could be used to create a virtual model in 3-D, which could then be dynamically colored to explore competing theories of coloring. It seems likely, for example, that the bold colors proposed so far are merely the undercoat of a subtler coloring, and would have been refined with layers of sophisticated overpainting. Three-dimensional graphics models of antiquities are now routinely used to illustrate and explore archaeological data (e.g., Pieta [Bernardini et al. 2002], Digital Michelangelo [Levoy et al. 2000]). Differences in pigments, lighting, and painting styles could all be explored and compared.

A good example of digital color reconstruction is the work done on rejuvenating the palette for Seurat's *Sunday on La Grande Jatte*, which hangs in the Art Institute in Chicago. The colors of the original painting, especially those containing zinc yellow, have darkened and yellowed over time. By simulating the physical properties of this pigment and translating them to color, Roy Berns and his colleagues have been able to simulate the original appearance of the painting (Berns n.d.).

Summary: Be Literate about Data, Skeptical about Pictures

In summary, the effective distillation of knowledge from information requires tools, one class of which is the abstracted graphical presentations called information visualizations. Digital information visualization provides potentially tremendous power, but also risk. Its effective design and use, like that of all powerful tools, requires education, training, and iterative refinement.

The hypermedia and computational underpinnings of Web 2.0 provide more-than-adequate technology. What is needed are insight and good design to apply this power to studies in the humanities. Most critical is active involvement by those most interested in the results. Their information goals must drive the tools, not the inverse.

Literacy in information analysis requires a willingness to grapple with data in all its untidy forms, including missing, incomplete, and contradictory entries. Good scholarship involves moving through layers of abstraction, using visualization to summarize, and drilling down to the supporting information structures. Good tools for scholarship must always include ways to view the underlying assumptions, to visualize and examine alternative interpretations, and to expose the degree of uncertainty.

The pictures generated as information visualization must be crafted with care and viewed with suspicion. Then they will correctly have the ability "to express 10,000 words."[5]

References

Ball, Phillip. 2003. *Bright Earth: Art and the Invention of Color*. Chicago: University of Chicago Press.

Bartram, Lyn, and Maureen Stone. Don't Scream: Characterizing Subtle Grids. Poster presentation at IEEE Visualization 2007, Oct. 28-Nov. 1, 2007, Sacramento, Calif.

[5] With due respect to Larkin and Simon (1987).

Bernardini, F., H. Rushmeier, I. M. Martin, J. Mittleman, and G. Taubin. 2002. Building a Digital Model of Michelangelo's Florentine Pieta. *IEEE Computer Graphics and Applications* 22(1): 59-67.

Berns, Roy S. n.d. *Rejuvenating Seurat's Palette Using Color and Imaging Science: A Simulation*. Available at http://www.cis.rit.edu/people/faculty/berns/seurat/Seurat_Berns_Essay_small.pdf.

Card, Stuart, Jock Mackinaly, Ben Shneiderman. 1999. *Readings in Information Visualization: Using Vision to Think*. San Francisco: Morgan Kaufman.

Few, Stephen. 2004. *Show Me the Numbers*. Oakland, Calif.: Analytics Press.

Gurewitsch, Matthew. 2008. True Colors. *Smithsonian* magazine (July).

Larkin, Jill H. and Herbert A. Simon. 1987. Why a Diagram is (Sometimes) Worth Ten Thousand Words. *Cognitive Science* 11(1): 65-100.

Levoy, M., K. Pulli, B. Curless, S. Rusinkiewicz, D. Koller, L. Pereira, M. Ginzton, S. Anderson, J. Davis, J. Ginsberg, J. Shade, and D. Fulk. 2000. The Digital Michelangelo Project: 3D Scanning of Large Statues. In *Proceedings of the 27th Annual Conference on Computer Graphics and Interactive Technique*, 131-144. New York: ACM Press/Addison-Wesley Publishing Co., New York, NY, 131-144.

Robison, Wade, Roger Boisjoly, David Hoeker, and Stefan Young. 2002. Representation and Misrepresentation: Tufte and the Morton Thiokol Engineers on the Challenger. *Science and Engineering Ethics* 8(1): 59-81. Guildford, Surrey, UK: Opragen Publications. Available at http://www.onlineethics.org/cms/17453.aspx.

Stone, Maureen, Sharon J. Laskowsi, and Svetlana Z. Lowry. 2008. *Guidelines for Using Color in Voting Systems*. National Institute of Standards and Technology (NISTIR 7537). Available at http://vote.nist.gov/NISTIR-7537.pdf.

Stone, Maureen, Lyn Bartram, and Diane Gromala. 2006. Great Grids: How and Why? In *ACM SIGGRAPH 2006 Research Posters*. International Conference on Computer Graphics and Interactive Techniques, July 30-Aug. 3, 2006, Boston, Mass. New York: ACM.

Stone, Maureen. 2003. *A Field Guide to Digital Color*. Wellesley, Mass.: A. K. Peters.

Tufte, Edward R. 2001 (1983). *The Visual Display of Quantitative Information*, second ed. Cheshire, Conn.: Graphics Press.

Tufte, Edward R. 1997. *Visual Explanations*. Cheshire Conn.: Graphics Press.

Tufte, Edward R. 1990. *Envisioning Information*. Cheshire Conn.: Graphics Press.

Ware, Colin. 2004. *Information Visualization: Perception for Design*, 2nd ed. San Francisco: Morgan Kaufman.

Web sites

Amiens Cathedral Web site: http://www.learn.columbia.edu/Mcahweb/Amiens.html

Google maps: http://maps.google.com/

IEEE Visualization Conferences: http://vis.computer.org/

Many Eyes: http://manyeyes.alphaworks.ibm.com

SmartMoney: http://smartmoney.com

Stephen Few's Web site: http://www.perceptualedge.com/

Tableau Software: http://www.tableausoftware.com/

University of Washington iSchool:
http://www.ischool.washington.edu/
The URL for the current course is:
http://courses.washington.edu/info424/ (this is the 2008 course).
The courses Zellweger and Stone taught are archived at:
http://courses.washington.edu/info424/2006/
http://courses.washington.edu/info424/2007/

U.S. Census Atlas: http://www.census.gov/population/www/cen2000/censusatlas/

Washington State Department of Transportation: http://www.wsdot.wa.gov/Traffic/seattle/