Principles of Information Display for Visualization Practitioners

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Introduction

This paper is intended to give the visualization practitioner an overview of Edward Tufte's work on information display. Dr. Tufte has written two classic books on information display: *The Visual Display of Quantitative Information* and *Envisioning Information*. I believe that many of the concepts in these books are important to scientific visualization, but are often not applied by practitioners.

Much of this paper is Tufte paraphrased; e.g., where Tufte might say `graphical excellence', I write `visualization excellence'. When you see the word `ink' (paper technology!), think `non-back-ground pixels'. Passages in quotation marks are direct quotes. Most of the text is a re-wording of Dr. Tufte's ideas, but all comments on the current state of visualization belong to me; and I am responsible for all errors.

The reader is encouraged to read Tufte's books. The treatment here is brief, incomplete, picture-poor, and low resolution.

Excellence

Visualization excellence

- "consists of complex ideas communicated with clarity, precision, and efficiency.
- is that which gives to the viewer the greatest number of ideas in the shortest time with the least ink in the smallest space.
- is nearly always multivariate.
- requires telling the truth about the data."

Visualizations should

- "show the data
- induce the viewer to think about the substance rather than about methodology, graphic design, the technology..., or something else
- avoid distorting what the data have to say
- present many numbers in a small space
- make large data sets coherent

- encourage the eye to compare different pieces of data
- reveal the data at several levels of detail, from a broad overview to the fine structure
- serve a reasonably clear purpose: description, exploration, tabulation, or decoration
- be closely integrated with the statistical and verbal descriptions of a data set."

Principles

Visualizations should strive towards the following goals:

- content focus
- comparison rather than mere description
- integrity
- high resolution
- utilization of classic designs and concepts proven by time.

Content Focus

"Above all else show the data." The focus should be on the content of the data, not the visualization technique. This leads to design transparency. Avoid "fooling around with data" and use a clear, simple, straight-forward design with a richness of data. The success of a visualization is based on deep knowledge and care about the substance, and the quality, relevance and integrity of the content.

Assume that the viewer is just as smart as you and cares just as much. Never `dumb-down' a visualization.

Comparison vs. Description

"At the heart of quantitative reasoning is a single question: Compared to what?" Most visualizations today are descriptive rather than comparative. This may be part of the reason why scientific graphics, even those about multivariate phenomenon, are dominated by the xy-plot. The xy-plot invites reasoning about causality in a way that even the most impressive isosurface does not. We should strive for relational, rather than merely descriptive, visualizations.

To focus a visualization on "Compared to what?" enforce visual comparisons, particularly within the eyespan. Avoid relying on the viewer's memory to make visual comparisons; a weak facility in most of us.

Integrity

Misleading visualizations are common. Although the following suggestions are tuned to statistical graphics, following a few of Dr. Tufte's rules may help limit unintentional visualization lies:

- "The representation of numbers, as physically measured on the surface of the graphic itself, should be directly proportional to the numerical quantities represented.
- Clear, detailed, and thorough labeling should be used to defeat graphical distortion and ambiguity.
- Write out explanations of the data on the graphic itself. Label important events in the data.
- Show data variation, not design variation.
- The number of information-carrying (variable) dimensions depicted should not exceed the number of dimensions in the data.
- Graphics must not quote data out of context."

There is even an equation to quantify one approach to lack of integrity, the lie factor. Lie-factor = size-of-effect-shown-in-visualization / size-of-effect-in-data.

High Resolution

Human eye registers 150 Mbits and can understand this avalanche of data because it is connected to a terrific editor: the brain. Consider some information sources in this context:

- 8 Mbits - good PC screen
- 24 Mbits - high end workstation screen
- 25 Mbits - 35mm slide
- 150 Mbits - large topographic map

Consider also the character density of some information forms:

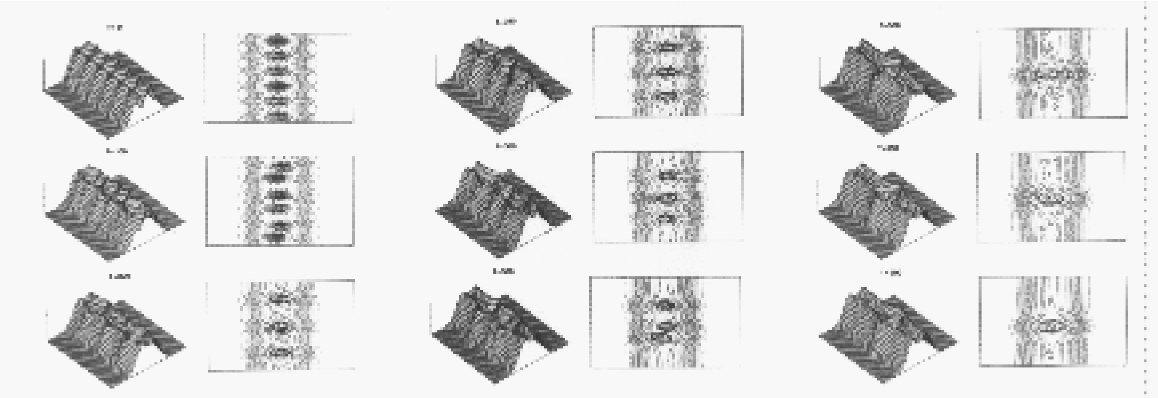
- 5-15 Kcharacters/page - non-fiction best sellers
- 10-18 Kcharacters/page - telephone books
- 28 Kcharacters/page - reference books

Nobody uses a 1200 baud modem when a 56 Kbit leased line is available. Similarly, we should not accept any less than the maximum information transfer rate for our visualizations. Not only is the information density of the computer screen somewhat low, it is further reduced in visualization packages that allocate only a smallish portion of the display to data and the rest to widgets and other "computer administrative debris."

Classic Designs

Tufte has researched a number of classic information designs and general principles. Some of these are small multiples, time series, and micro/macro composition.

Small Multiples



A. Ghizzo, B. Izrar, P. Betrand, E. Fijalkow, M. R. Feix, and M. Shoucri, "Stability of Bernstein-Greene-Kruskal Plasma Equilibria: Numerical Experiments Over a Long Time," *Physics of Fluids*, 31 (January 1988).

A small multiple design consists of a single design repeated several times within the eyespan, each example showing a different value of the independent variable(s). "Comparison must be enforced within the scope of the eyespan," a task at which small multiples excel. Thus, "for a wide range of problems in data presentation, small multiples are the best design solution." "At the heart of quantitative reasoning is a single question: *Compared to what?* Small multiple designs, multivariate and data bountiful, answer directly by visually enforcing comparisons of changes, of the differences among objects, of the scope of alternatives."

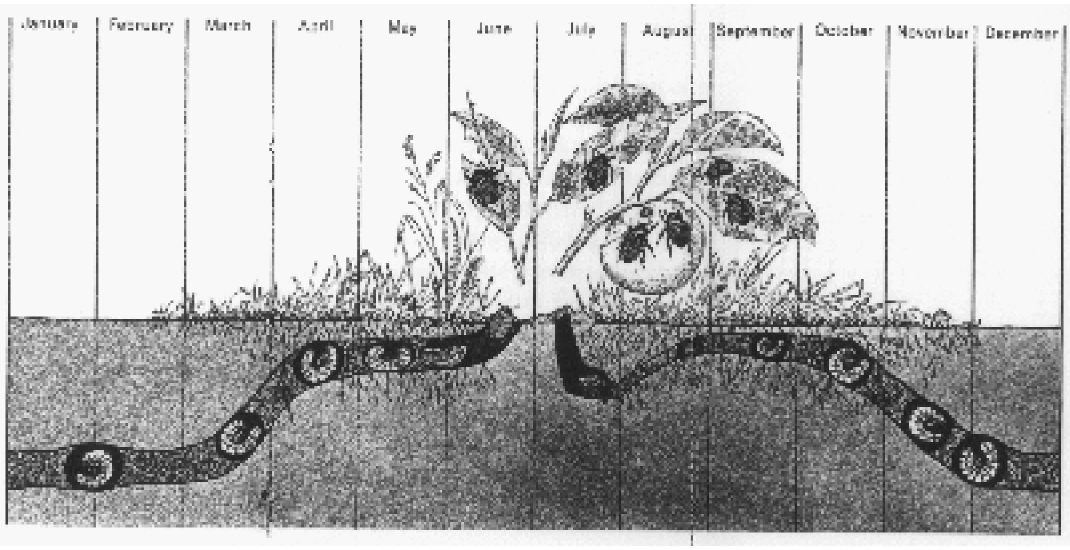
"Well designed small multiples are

- inevitably comparative
- deftly multivariate
- shrunken, high density graphics
- usually based on a single large data matrix
- drawn almost entirely with data-ink
- efficient in interpretation
- often narrative in content, showing shifts in the relationship between variables as the index variable changes (thereby revealing interaction or multiplicative effects)."

Note that "simultaneous two-dimensional indexing of the multiplied image, flatland within flatland, significantly deepens displays, with little added complication in reading."

Small multiples are a straightforward extension to many current visualization systems, although graphics performance may be a problem.

Time Series



L. Hugh Newman, *Man and Insects* (London, 1965), pp. 104-105.

"The time-series plot is the most frequently used form of graphic design." One dimension, usually the horizontal, is time, and the graphics march along showing variation as time proceeds. Most visualization time-series works are videos, which show time by changing the picture, requiring the user to remember what came before. Finding innovative ways to incorporate time-series into visualization systems should be given serious consideration.

Micro/Macro Composition

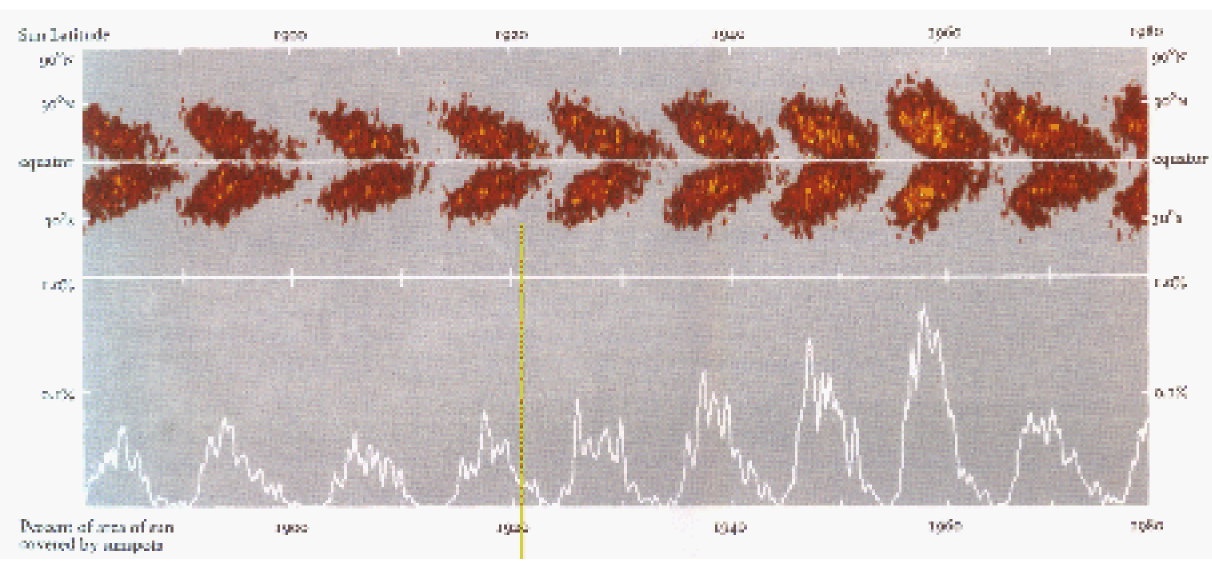


Diagram by David H. Hathaway, Marshall Space Flight Center, NASA.

Micro/macro composition refers to an approach where a visualization contains enormous detail, but an overall pattern emerges. "Panorama, vista, and prospect deliver to viewers the freedom of choice that derives from an overview, a capacity to compare and sift through detail. And that micro-information, like smaller texture in landscape perception, provides a credible refuge where the pace of visualization is condensed, slowed, and personalized."

Design Guidelines

This section summarize design guidelines and principles found in Tufte's work. Visualizations "are paragraphs about data and should be treated as such." Words, pictures, and numbers are all part of the information to be visualized. All should be integrated together, not separated into word processor documents, spread sheet tables, and visualization package screens. Here are some guides for workaday designs:

- "have a properly chosen format and design
- use words, numbers, and drawing together
- reflect a balance, a proportion, a sense of relevant scale
- display an accessible complexity of detail
- often have a narrative quality, a story to tell about the data
- are drawn in a professional manner, with the technical details of production done with care
- avoid content-free decoration, including chartjunk"

Definition: *Chartjunk* - miscellaneous graphic gunk attached to a chart (visualization) that has nothing to do with the data and everything to do with poor taste.

Data-ink ratio

There is at least one quantitative measure of a visualization, here expressed in terms of ink rather than pixels. The translation is straightforward.

"Data-ink ratio = data-ink / total ink used to print the graphic = proportion of a graphic's ink devoted to the non-redundant display of data-information = 1.0 - proportion of a graphic that can be erased without loss of data-information"

One should

- "maximize the data-ink ratio, within reason"
- "erase non-data-ink, within reason"
- "erase redundant data-ink, within reason"

This leads to tight visualizations with a minimum of extraneous junk. We see that "for non-data-ink, less is more. For data-ink, less is a bore." This suggests five principles of data graphics:

- "Above all else show the data.
- Maximize the data-ink ratio.
- Erase non-data-ink.
- Erase redundant data-ink.

- Revise and edit."

Just as good prose is often the result of revision and editing, good visualization requires criticism and rework.

An interesting example of non-data ink erasure is range frames. The frame of an xy-plot is non-data ink. Most of the frame can be erased without loss of information, and if only the portion of the frame between minimum and maximum values is left, the frame provides additional information!

Clutter

When viewing a visualization jammed with incomprehensible, cluttered graphics, there is a great temptation to remove data; even relevant information. But "clutter and confusion are failures of design, not attributes of information." If a visualization is too cluttered, don't remove data, change the design. Credibility comes from detail and in many cases one can clarify a design by adding detail. "High-density designs also allow viewers to select, to narrate, to recast and personalize data for their own uses. ... Data-thin, forgetful displays move viewers toward ignorance and passivity, and at the same time diminish the credibility of the source."

Empty space may reduce clutter, but "it is not how much empty space there is, but rather how it is used. It is not how much information there is, but rather how effectively it is arranged."

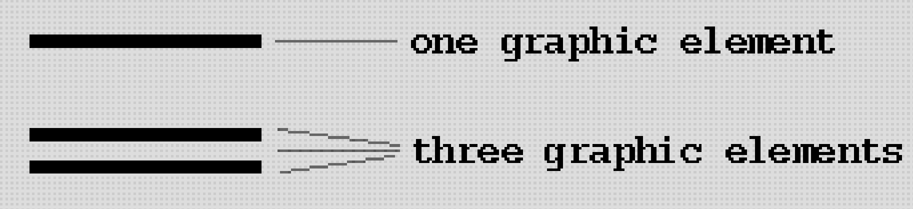
Low density computer displays lead to spreading information out over many screens or dialog boxes. This leads to the "one damn thing after another" syndrome which causes users to get lost in an information maze. Place information adjacent in space, not stacked in time, to avoid the `Where am I?' problem.

Layering and Separation

Consider a colormapped surface that requires annotation. If the colormap uses all possible colors, positioning annotation will be difficult because of color clashes. A better approach might be to use intensity of a single hue for the colormap, leaving visual space for addition information; i.e., the annotation. This is an example of layering and separation. Layering and separation implies using color or other differentiation to separate important classes of information. Maps are often very good examples of this technique.

1 + 1 = 3 or More

But "effective layering of information is often difficult... (because) an omnipresent, yet subtle, design issue is involved: the various elements collected together... *interact*, creating non-information patterns and texture." "Josef Albers described this visual effect as *1 + 1 = 3 or more*."



For example, consider a single line -- a single graphic element. Now consider two parallel lines. Here we have at least three graphical elements, each of the lines and *the space between them*. This 1 + 1 = 3 or more effect is important, and "most of the time, that surplus visual activity is non-information, noise, and clutter." However, "the noise of 1 + 1 = 3 is directly proportional to the contrast in value (light/dark) between figure and ground. On white backgrounds, therefore, a varying range of lighter colors will minimize incidental clutter."

A particularly common example of 1 + 1 = 3 or more is boxes around text. "Unless deliberate obscurity is sought, avoid surrounding words by little boxes, which activate negative white spaces between word and box." Note that the box is non-data ink.

Color

"The fundamental uses of color in information design (are): to label, to measure, to represent or imitate reality, to enliven or decorate." Dr. Tufte provides a few specific guidelines on the use of color:

- "Color spots against a light gray or muted field highlight and italicize data." "Note the effectiveness and elegance of *small spots of intense, saturated color* for carrying information."
- "use colors found in nature, especially those on the lighter side."
- "For encoding information,... more than 20 or 30 colors frequently produce not diminishing but negative returns."
- "The primary colors (yellow, red, blue) and black provides maximum differentiation (no four colors differ more)."
- In color maps, use a single hue, Don't use up the entire color spectrum, or even all of a hue's levels. Particularly avoid Roy G. Biv (red, orange, yellow, green, blue, indigo, violet), the color spectrum of the rainbow. It's good physics, but poor human factors. Like all multi-hue color maps, the non-equidistant hue changes are perceived as especially important contours, which they usually are not. Furthermore, the lighter middle parts of the spectrum are often perceived as the higher values. Finally, one needs to constantly remind oneself which color means high vs. low values. Using a single hue with variations in intensity allows instant interpretation, multiple color maps without ambiguity, and leaves graphical space for layering and separation.

Tufte turns to the Swiss cartographer, Eduard Imhof for additional insight:

- "Pure, bright or very strong colors have loud, unbearable effects when they stand unrelieved over large areas adjacent to each other, but extraordinary effects can be achieved when they are used sparingly on or between dull background tones."

- "The placing of light, bright colors mixed with white next to each other usually produces unpleasant results, especially if the colors are used for large areas."
- "Large area background or base-colors should do their work most quietly, allowing the smaller, bright areas to stand out most vividly, if the former are muted, grayish or neutral."
- "If a picture is composed of two or more large, enclosed areas in different colors, then the picture falls apart. Unity will be maintained, however, if the colors of one area are repeatedly intermingled in the other...."

"Color itself is subtle and exacting. And, furthermore, the process of translating perceived color marks on paper into quantitative data residing in the viewer's mind is beset by uncertainties and complexities. These translations are nonlinear (thus gamma curves), often noisy and idiosyncratic, with plenty of differences in perception found among viewers (including several percent who are color-deficient)."

Miscellaneous Admonitions

- "Above all, do no harm."
- Avoid codes, particularly one-time codes and legends. Place legends directly on the visualization.
- Use the smallest effective distance. "Make every visual move as small as possible, but keep clarity."
- "Mobilize every graphical element, perhaps several times over, to show the data."
- Tone down grids. Heavy, dominating grids often mar a graphic, overwhelming the data. Draw grids with a thin line and a light color, preferably grey. Let the data stand out.
- For a few numbers, use a table.
- "Transparent and effective deployment of redundant signals requires, first, the need--an ambiguity or confusion in seeing a data display that can in fact be diminished by multiplicity--and second, the *appropriate choice of design technique*."
- There are lots of good graphical designs. You needn't invent more. *Re*search the literature, find good information designs, and steal them. Remember that talent imitates, genius steals.
- "Graphics should tend toward the horizontal, greater in length than in height. If the nature of the data suggests the shape of the graphic, follow that suggestion. Otherwise, move toward horizontal graphics about 50 percent wider than tall"
- Those that do the work should get the credit, sign your work.

Parting Shots

After a detailed analysis of sunspot diagrams developed over a few centuries, Tufte writes:

> "Note all the different techniques for displaying sunspots during 380 years of data analysis -- from Galileo's first precious observation of the solar disks, to small multiple images, to dimensionality and data compression, and finally to micro/macro displays combining pattern and detail, average and variation. Exactly the same design strategies are found, again and again, in the work of those faced with a flood of data and images, as they

> scramble to reveal, within the limits of flatland, their detailed and complex information. These design strategies are surprisingly widespread, albeit little appreciated, and occur quite independently of the content of the data. "

"Graphical competence demands three quite different skills: the substantive, statistical, and artistic." Visualization competence requires no less.

References

Edward Tufte *The Visual Display of Quantitative Information* and *Envisioning Information*, Graphics Press, PO Box 430, Cheshire, CT 06410.