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Graphics and Web Design Based on Edward Tufte's Principles

This is an outline of Edward Tufte's pioneering work on the use of graphics to display quantitative information. It mainly consists of text and ideas taken from his three books on the subject along with some additional material of my own. This page is in text only format: in order to understand the concepts you need to read the books because the concepts cannot really be grasped without the illustrations, and current video monitor technology is too low in resolution to do them justice. His work has been described as "a visual Strunk and White" (here is a German translation of this article).

Throughout this outline I have included references to the illustrations in his books that are labeled with the abbreviations VD-pp, VE-pp, and EI-pp, where "pp" is a page number and:

- VD is "the Visual Display of Quantitative Information"
- VE is "Visual Explanations"
- EI is "Envisioning Information"

Outline

Introduction

Tufte's works address the following issues:

- The Problem: The problem is that of presenting large amounts of information in a way that is compact, accurate, adequate for the purpose, and easy to understand. Specifically, to show cause and effect, to insure that the proper comparisons are made, and to achieve the (valid) goals that are desired.
- Its Importance: Printed and graphical information is now the driving force behind all of our lives. It no longer is confined to specialized workers in selected fields but impacts nearly all people through the widespread use of computing and the Internet. Rapid and accurate transfers of information can be a life and death matter for many people (an example being the Challenger disaster). The extent to which symbols and graphics affect our lives can be seen by the dramatic increase in IQ scores in all cultures which have acquired information technology: in the United States there has been an average increase of 3 IQ points per decade over the last 60 years, for a total of an 18 IQ point increase. There is no known biological explanation for this increase and the most likely cause is widespread exposure to text, symbols, and graphics that accompany modern life. As mentioned above, this increase has been seen in all cultures exposed to information technology.
- Its Application: Some of the information relates to the displays of statistical information, but much applies to any type of display, even plain text.

- The Solution: To develop a consistent approach to the display of graphics which enhances its dissemination, accuracy, and ease of comprehension.

History of Plots

The very first known plot dates back to the 10-th century (VD-28: first known graph). This was about the same time that Guido of Arezzo was developing the two-dimensional musical staff notation very similar to the one we use today. In the 15-th century Nicolas of Cusa developed graphs of distance versus speed. In the 17th century Rene Descartes established analytic geometry which was used only for the display of mathematical functions. But the main initiator for informative graphics was William Playfair (1759-1823) who developed the line, bar, and pie charts as we know them today.

The Explanatory Power of Graphics

The importance and explanatory power of graphics can be seen in these examples:

- Illustration VD-13/14 shows 4 plots which have a large number of absolutely identical statistical measures and properties and yet are very different, as can be immediately seen from their graphs.
- The Challenger disaster: the data graphs shown to NASA did not convey the real information which was needed (VE-47 versus VE-45). If NASA had seen the appropriate, but very simple, graphics which showed the effects of low temperature and damage to the solid rocket boosters, the Challenger would not have been launched that (very cold) day.
- The Broad Street Pump cholera epidemic in 1854 in

London, as displayed by John Snow (VE-31: cholera deaths). This graph showed clusters of cholera deaths around the site of the pump.
- Illustration VD-166: "communes in France" shows an extremely dense plot which displays the boundaries of more than 30,000 communes in France.

Basic Philosophy of Approach

Important rules and themes to use when presenting graphics:

- Assume that the audience is intelligent (a paraphrase from E.B. White). Even publications, such as NY Times, assume that people are intelligent enough to read complex prose, but too stupid to read complex graphics.
- Don't limit people by "dumbing" the data -- allow people to use their abilities to get the most out of it.
- To clarify -- add detail (don't omit important detail; e.g., serif fonts are more "detailed" than san serif fonts but are actually easier to read). And Einstein once said that "an explanation should be as simple as possible, but no simpler".
- Above all else, show the data. Graphics is "intelligence made visible"
- Data rich plots can show huge amounts of information from many different perspectives: cause & effect, relationships, parallels, etc. (VD-31: train schedule, VD-17: Chloroplethic map, VD-41: Napoleon's campaign, EI-49: space junk)
- Plots need annotation to show data, data limitations, authentication, and exceptions (VE-32: text of exceptions)
- Don't use graphics to decorate a few numbers

Graphical Integrity

In addition to "lies, damn lies, and statistics", graphics can also be used to deceive. For example, deceptive graphics may:

- Compare full time periods with smaller time periods (VD-60: Nobel prizes, which compares 10 year time periods with one 5 year period)
- Use a "lie factor" [= (size of graphic)/(size of data)] to exaggerate differences or similarities
- Use area or volume representations instead of linear scales to exaggerate differences. See VD-69: "Shrinking family doctor" as an example of how to confuse people using 1 versus 2- and 3- dimensional size comparisons. Area and volume representations fool people with the square/cube law: an increase in linear size leads to a square of the increase for areas and a cube of the increase for volumes.
- Fail to adjust for population growth or inflation in financial graphs
- Make use of design variation to obscure or exaggerate data variation (VD-61: exaggeration of OPEC prices)
- Exaggerate the vertical scale
- Show only a part of a cycle so that data from other parts of the cycle cannot be used for proper comparison

Graphical errors may be more common today than in the past due to the easy and frequent use of computers. Guidelines to help insure graphical integrity include the following:

- Avoid chartjunk
- Don't dequantify: provide real data as accurately as is reasonable. For example, ranking products as better or worse according to one criteria when several factors are involved is often not useful unless the magnitudes of the differences are indicated.
- Don't exaggerate for visual effects, unless it is needed to convey the information. Sometimes such exaggerations are essential: for example, it is virtually impossible to show both the size and the orbits of planets at the right scale on the same chart. On the other hand, illustration VE-24: "Exaggerated vertical Venus scale", shows such dramatic mis-information, that one researcher called for the formation of "a flat Venus society".
- Avoid dis-information: thick surrounding boxes and underlined san serif text make reading more difficult

- Watch out for effects of aggregation: e.g., dot maps are often more honest in this respect than chloroplethic maps which group results based on (sometimes arbitrary) boundaries.
- Ask the right questions:
    1. Does the display tell the truth
    2. Is the representation accurate
    3. Are the data documented
    4. Do the display methods tell the truth
    5. Are appropriate comparisons, contrasts, and contexts shown

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Data Densities

Graphics are at their best when they represents very dense and rich datasets. Tufte defines data density as follows:

Data density = (no. of entries in data matrix)/(area of graphic)

Note that low data densities on computer displays force us to view information sequentially, rather than spatially, which is bad for comprehension. Good quality graphics are:

- Comparative
- Multivariate
- High density
- Able to reveal interactions, comparisons, etc
- And where nearly all of the ink is actual data ink

Example data densities include:

- 110,000 numbers/sq-inch for an astronomical graph. This is the maximum known density for a graph. For most scientific journals we get about 50-200 numbers/sq-inch

- 150 Mbits = human eye
  8 Mbits = typical computer screen
  25 Mbits = color slide

150 Mbits = large foldout map
28,000 Characters = Reference book
18,000 Characters = phone book
15,000 Characters = non-fiction

An excellent example of a data rich plot is a graphical train schedule (VD-31: train schedule) which shows start and stop times, locations, directions, routes, transfers, and speeds all on one sheet of paper.

Data Compression

- Use data compression to reveal (not hide) data . For example, EI-22: "Sun Spot cycles" displays sunspots as thin vertical lines in the y-axis direction only in order to present many such spots over a period of time on a single graph
- Use compression to show lots of information in a single graph, such as a plot that shows x-axis, y-axis, and x/y interactions. (VD-134: Pulsar signals; VE-111)
- Exclude bi-lateral symmetry when it is redundant (e.g., charnoff faces) or extend it when it aids comprehension (50% more view of the world on a world map provides a wrap-around context that aids understanding). Studies show that we often concentrate on one side of a symmetrical figure and only glance at the other side.

Multifunctioning Graphical Elements

Graphical structures can often serve several purposes once. For example,

- Stem and leaf plots display sequences of numbers which directly portray structure by the physical length of each sequence. (VD-140: stem/leaf; VD-141: army divisions; VD-143: Normal curve)

- The Consumer Reports listing of automobile defects (VD-174: Consumer Reports) reveal a micro/macro structure: the overall display of black ink immediately reveals which cars are most troublesome, whereas each individual element in the display identifies a particular weakness.
- The data grid itself may be the data, revealing both the values and the coordinate system at the same time (VD-152: data-based markers)

Maximize Data-ink; Minimize non-Data Ink

Tufte defines the data ink ratio as:

Data Ink Ratio = (data-ink)/(total ink in the plot)

The goal is to make this as large as is reasonable. To do this you:

- Avoid heavy grids
- Replace box plots with interrupted lines (VD-125: reduced box plot)
- Replace enclosing box with an x/y grid
- Use white space to indicate grid lines in bar charts (VD-128: white spaces)
- Use tics (w/o line) to show actual locations of x and y data
- Prune graphics by: replacing bars with single lines, erasing non-data ink; eliminating lines from axes; starting x/y axes at the data values [range frames])
- Avoid over busy grids, excess ticks, redundant representation of simple data, boxes, shadows, pointers, legends. Concentrate on the data and NOT the data containers.
- Always provide as much scale information (but in muted form) as is needed

Small Multiples

Small multiples are sets of thumbnail sized graphics on a single page that represent aspects of a single phenomenon. They:

- Depict comparison, enhance dimensionality, motion, and are good for multivariate displays (VD-114: particle momentum)
- Invite comparison, contrasts, and show the scope of alternatives or range of options (VE-111: medical charts)
- Must use the same measures and scale.
- Can represent motion through ghosting of multiple images
- Are particularly useful in computers because they often permit the actual overlay of images, and rapid cycling.

Chartjunk

Chartjunk consists of decorative elements that provide no data and cause confusion.

- Tufte discusses the rule of 1+1=3 (or more): 2 elements in close proximity cause a visible interaction. Such interactions can be very fatiguing (e.g., moiré patterns, optical vibration) and can show information that is not really there (EI-60: data that is not there, VD-111: chart junk)
- In major science publications we see 2% to 20% moiré vibration. For example, in recent statistical and computer publications chartjunk ranges from 12% to 68%
- Techniques to avoid chartjunk include replacing crosshatching with (pastel) solids or gray, using direct labeling as opposed to legends, and avoiding heavy data containers

Colors

Colors can often greatly enhance data comprehension.

- Layering with colors is often effective
- Color grids are a form of layer which provides context but which should be unobtrusive and muted
- Pure bright colors should be reserved for small highlight areas and almost never used as backgrounds.
- Use color as the main identifier on computer screens as different objects are often considered the same if they have the same color regardless of their shape, size , or purpose
- Contour lines that change color based on the background standout without producing the 1+1=3 effects
- Colors can be used as labels, as measures, and to imitate reality (e.g., blue lakes in maps).
- Don't place bright colors mixed with White next to each other.
- Color spots against a light gray are effective
- Colors can convey multi-dimensional values
- Scroll bars should be solid pastel colors
- Note that surrounding colors can make two different colors look alike, and two similar colors look very different (EI-92/93: effects of context on colors).
- Subtle shades of color or gray scale are best if they are delimited with fine contour lines (EI-94: shades with contours)
- Be aware that 5-10% of people are color blind to some degree (red-green is the most common type followed by blue-yellow, which usually includes blue-green)

General Philosophy for Increasing Data Comprehension

- High density is good: the human eye/brain can select, filter, edit, group, structure, highlight, focus, blend, outline, cluster, itemize, winnow, sort, abstract, smooth, isolate,

idealize, summarize, etc. Give people the data so they can exercise their full powers -- don't limit them.
- Clutter/confusion are failures of design and not complexity
- Information consists of differences that make a difference: so you can "hide" that data which does not make a difference in what you are trying to depict
- In showing parallels, only the relevant differences should appear
- Value and power of parallelism: once you have seen one element all the others are accessible
- Important concepts in good design: separating figure and background (for example, a blurry background often brings the foreground into sharper focus), layering & separation, use of white space (e.g., Chinese landscapes emphasize space, as in the painter known as "one corner Ma"; oriental music is often there to emphasize the silence and not the sound).
- Graphics should emphasize the horizontal direction

Techniques for Increasing Data Comprehension

To increase data comprehension you:

- Make marks or labels as small as possible, but as small as possible to still be clear.
- Avoid pie charts as they are low density and fail to order values along a visual dimension
- Usually use dot maps in place of chloroplethic maps because they show more exact detail
- Closely interweave text and graphics: attach names directly to parts, place small messages next to the data, avoid legends if possible and annotate the data directly on the graph (VE-99: anatomy of a font)
- Avoid abbreviations if possible, and use horizontal text
- Use serif fonts in upper/lower case
- Use transforms of scaling if they (honestly) can reveal information which might otherwise be overlooked.
- Use different structures to reveal 3D and motion, such as

the exploded hexagon, true stereo, and extreme foreshortening (as on the edge of a sphere: see EI-15 "exploded hexagon")

When NOT to Use Graphics

- Often text tables can replace graphs for simple data; you can also use 2D text tables, where row and column summaries are useful. Non-comparative data sets usually belong in tables, not charts
- Poster designs are meant just to capture attention, as opposed to conveying information -- generally they are not good designs for graphs.
- If a picture is not worth a 1000 words, to hell with it (quote from Ad Reinhardt -- note this is from the original Chinese quote that "a picture is worth 10,000 words).

Aesthetics

Graphical excellence consists of simplicity of design and complexity and truth of data. To achieve this

- Use words, numbers, drawings in close proximity
- Display an accessible complexity of data
- Let the graphics tell the story
- Avoid context-free decoration
- Use lines of different weights as an attractive and compact way to display data (VD-185: Mondrian)
- Make use of symmetry to add beauty (although someone once said that "all true beauty requires some degree of asymmetry")

Other Topics: **Other References**