Visualization Techniques for the Display of Graphs

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Systems often require the display of graphs to represent the information stored in the datasets. Developers frequently find it difficult to visualize these datasets correctly. Often this is done incorrectly as the visual variables and their relative characteristics are usually not taken into account. By using these visual variables appropriately and following certain guidelines of graphic creation, a graphic can convey the meaning more clearly. Supplementing this value attained with the use of interactivity can add a new dimension of intuitiveness to the graphic. When following this formal way of tackling graph creation, better graphics are likely to be the result.

1. BACKGROUND

In today's fast changing environment technology is getting more powerful by the day. We are seeing storage devices that can handle the overload of data that we are presented with in industry. This data has meaning that can add priceless value to its owners. The problem we are faced with is that the data's value is hidden to us, that is we are unable to make sense of the massive amounts of numerical and textual data as the trends are unapparent in this format.

The solution to this problem is to visualize this information in the form of a graphic. Until recently the definition of visualization meant, "a mental vision, image, or picture of (something not visible or present to sight, or of abstraction)" as defined in The Oxford English Dictionary. It has now come to mean the graphical representation of data or the transformation of information into images to support decision making [Ware 2000]. Once visualized, hidden trends become more obvious and the data's value can truly become a reality. However, the use of graphics to convey meaning from datasets is not a new concept. People have been creating graphics to convey their messages for thousands of years, from famous graphics such as those drawn of Napoleon's March on Moscow to today's graphs used in data warehousing to uncover trends [Tufte 1999b]. What we don't know, however, is how to convey our messages correctly. The meaning we wish to communicate often gets lost in graphics that are cluttered and that make use of visuals which do not work well together.

A formal way to think about the construction of graphics is suggested, taking into account what can and what shouldn't be done when visualizing information. This includes how to convey the intended meaning correctly. This can be done by understanding what core concepts will affect the message of the graphic. Visual variables can be used to provide this meaning, and taking advantage of the visual variables characteristics can also prove to be extremely beneficial.

One of the greatest benefits of information visualization is presenting large amounts of data that can easily be interpreted [Ware 2000]. When visualizing this amount of data detail can be lost as an overview or summary is often all that can be displayed in the space provided for the graphic. Incorporating an interactive element into your graphic can therefore play an important role as it allows viewers to see an overview of the graphic and then get further details on areas that are of interest to them at will.

These concepts are focused around helping to create better, more functional graphs. They can however be applied to most graphics as the guidelines proposed pertain to more than just line graphs. It can be seen more as a universal way of thinking when it comes to the creation of better graphics.

2. VISUALIZATION PRINCIPLES

Through the use of visualization principles much value can be given to a graphic. This value comes in the form of the stimulation received from the graphic which helps to give the viewer an understanding of the visual that would have been difficult to convey otherwise [Köbben and Yaman 1995].

There are eight visual variables that are documented and provide a way to convey information [Bertin 1983].

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The first visual variable is position, these represent changes in the x, y, and z (if z coordinates exist) coordinates on the graphic. Following that is size, which can represent a change in length or area. Third is shape. Value, which is fourth, represents a change from light to dark. Next is orientation, this shows a change in alignment. Colour is another visual variable and can take on as many values as the eye can distinguish. Texture symbolizes a change in pattern, and the final variable defined is motion [Carpendale 2001].

The visual variables as defined by Bertin provide information, however the stimuli that is provided by the graphic to the user comes from the characteristics of the visual variables. These characteristics, also known as perceptual properties provide meaning to the graphic [Köbben and Yaman 1995]. There are five properties of visual variables, these properties show association, enable selection, quantify and order variables, and distinguish the length of the variables. Association and selection are sometimes combined, or fall under a common category of nominal values. This means that these values have no ordering relationship, but five basic perpetual properties are still recognized and provide invaluable meaning to a visual [Miller 2003].

2.1 Selection

A visual variable can be seen as being selective when isolating a specific instance of the variable is effortless [Varey 2002]. Locating the variable should be easy, most variables are selective, however shape is not. It is easy to locate a green object from a bunch of other coloured objects, but locating a triangle in between a sea of rectangles is a lot more difficult and thus shape is not selective [Miller 2003]. As we can see in Figure 1 (a), the visual variables of size and value exhibit the characteristic of selection. It is easy to distinguish between a big circle and a small one. Distinguishing between a light circle and a dark one is also effortless.

2.2 Association

Association of variables is true when a change in the variables is enough for us to associate them into a group [Carpendale 2001]. They therefore have to exhibit similar properties. Association is useful to indicate groups of different quality [Köbben and Yaman 1995]. Figure 1 (a) shows that size also exhibits the characteristic of association as the small circles, big circles, and triangles can be grouped based on their size.

2.3 Quantitative

Visual variables are quantitative when changes to the variable represent numerical changes [Carpendale 2001]. The graphic can therefore indicate differences quantitatively. In Figure 1 (b) we can see that a change in the visual variable of position shows the characteristic of quantity as a variation in the x and y coordinates relates to a change in value on the vertical and horizontal axis.

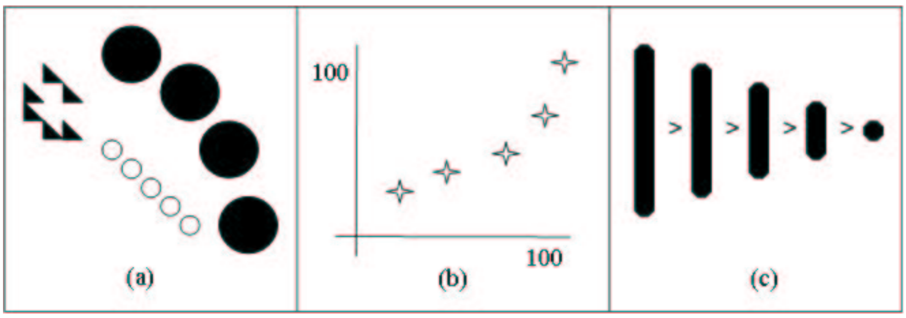

Figure 1. Model of a perception

2.4 Order

When changes occur in the visual variable this characteristic helps to show if those changes are ordered [Carpendale 2001]. Objects could therefore be ranked in order if they have this characteristic [Varey 2002]. As Figure 1 (c) illustrates, a change in the size of the oval can be ordered from biggest to smallest.

2.5 Length

Length distinguishes how many distinctions are observable as this variable changes [Carpendale 2001]. Figure 1 (c) also shows that size can have the characteristic of length. Theoretically there can be an infinite amount of differences in the ovals size, but the number of them that are distinguishable depends on the size of your graphic. The general heuristic is to limit the use of size to about 20 distinguishable variations [Carpendale 2001].

A more detailed relation between which visual variables exhibit which characteristics is shown in Figure 2 in the next section.

The characteristics or properties of the visual variables play an important roll when adding meaning to graphics as well as to the visual variable themselves. Using these variables however is not the easiest thing to do correctly. Some guidelines have to be drawn up to help ensure that graphics are drawn clearly and meaningfully.

3. CONSTRUCTING GRAPHS - GUIDELINES

There are a number of guidelines that should be followed when visualizing quantitative information. These guidelines will help convey meaning about the graphic to the viewer. Some of these guidelines may be less obvious than others when creating the graphic.

Deciding which guidelines to follow and which to ignore has a lot to do with what you are visualizing. The outcome should tell a story, as well as exhibit good design principles. The user should be kept in mind the whole time when graphs are being drawn up. This involves thinking how certain additions to the graphic will affect the user emotionally. Positive emotions will allow the user to think more clearly about complex situations, whereas negative emotions force the user into a negative mindset and is therefore less productive [Dix et al. 2004]. Graphical grace is often found in simplicity of design and intricacy of the data [Tufte 1999b]. Consider some of these guidelines which are focused around using Bertin's list of visual variables.

The first visual variable is that of position. A variable changes in position when a point or an object on a graph exhibits a change in its x, y, or z coordinates. Note that if two-dimensional graphic will only exhibit a change in its x or y coordinate, where as a three-dimensional graphic can show a change in the z coordinate as well as it has the added dimension of depth [Carpendale 2001]. Currently, visualization tools have been making use of multiple two-dimensional views to show three-dimensional as well as other multidimensional spaces. This may be attributed to two-dimensional positions being easier to reflect on a two-dimensional screen [Shneiderman 2004].

Changes in size are shown by a change in the length, area or even volume in the case of three-dimensional graphics [Carpendale 2001]. This affects the proportion and scale which play an important role in the display of information. A contrast in line weight represents a contrast in meaning. The line with the greater meaning has the greater line weight and should therefore represent the data. The weight of the lines representing the grid on which the data is plotted should be thin and faint. The grid should merely be an aid in reading the graph and not affect the readability of the data line [Tufte 1999b].

The third visual variable shape, can take on an infinite amount variations. A change in a shapes size does not constitute a change in its shape though, that is a big triangle and small triangle are not seen as two unique shapes [Carpendale 2001].

A change in value is represented by a change from light to dark of an object on the graphic [Carpendale 2001]. This visual variable is very powerful as it can represent emotions, space, movement, and the illusion of light. It has been seen that dark areas have emotions of gloom or mystery attached to it while light areas represent warmth and a feeling of calmness. This doesn't mean you should not use black in a graphic, it rather means you should take into account the feeling you want the viewer to experience and use the value variable appropriately [Varey 2002]. Lighting also provides an effective means to display the surface shape of data sketched in graphs [The MathWorks 2004]. By fading the brightness the perception of distance or depth can be reached and therefore a feeling of intensity appears [Domik 1999]. People find it much easier to distinguish variations in brightness than say in hue or saturation differences [Meier 1988].

Closely related to value is the visual variable of colour. This is a very powerful variable and can take on as many variations as the eye can distinguish. Changing the colour of a variable is seen as changing the hue without changing the value [Bertin 1983]. Using a rainbow scale to represent changes in colour can prove to affect the interpretation of a graphic incorrectly. This should be taken into account when creating a graphic and care must be taken to convey your intended meaning correctly [Carpendale 2001]. Introducing colour to information is not easy, "avoiding catastrophe becomes your first goal" [Tufte 1999a]. Colour is good at conveying data values, both constant and varying, and is a major contribution to the conveyance of emotion [The MathWorks 2004]. There are powerful emotions attached to each colour and a mood can be enhanced or aggravated by the colour chosen. Certain colours or combinations of colours can make viewers feel uneasy or upset, or could have the opposite effect and convey feelings of joy and happiness. Colour can affect the perception of depth in a graphic as well. A red block placed on a blue background will appear closer than a blue block on a red background [Birn 2000]. Also colour is associative, meaning that marks belonging of the same colour can be grouped into a category [Bertin 1983].

Orientation changes when changing the alignment of a line or an area on a graphic. This can be achieved by changing the angle of a line in which a pattern is applied [Carpendale 2001].

A guideline related to orientation is that graphics should lean towards being drawn horizontally, that is greater in length than in height. Ours eyes are practiced to the horizon and it is therefore easier to read graphs that are greater in length. It is also easier to read text on the graph from left to right, rather than from top to bottom. Sketching graphs horizontally makes it easier to increase the detail of the causal variable, which is represented by the horizontal access. The vertical axis normally represents effect [Tufte 1999b].

Texture is a variation in grain. Bertin defines texture as, "texture variation is the sensation resulting from a series of photographic reductions of a pattern of marks" [Bertin 1983].

Bertin did not include motion as one of his visual variables as he said it would dominate the visual variables he distinguished and interfere with the message or meaning trying to be conveyed. Further research into the effectiveness of motion has shown that it would indeed add meaning and give the message that is trying to be conveyed a new dimension [Köbben and Yaman 1995].

These visual variables display certain characteristics as illustrated in Figure 2. The characteristics were discussed in the previous section. The graphic shows that a certain characteristic may always be related to a visual variable, only display the characteristic on occasion, or never exhibit the characteristic at all.

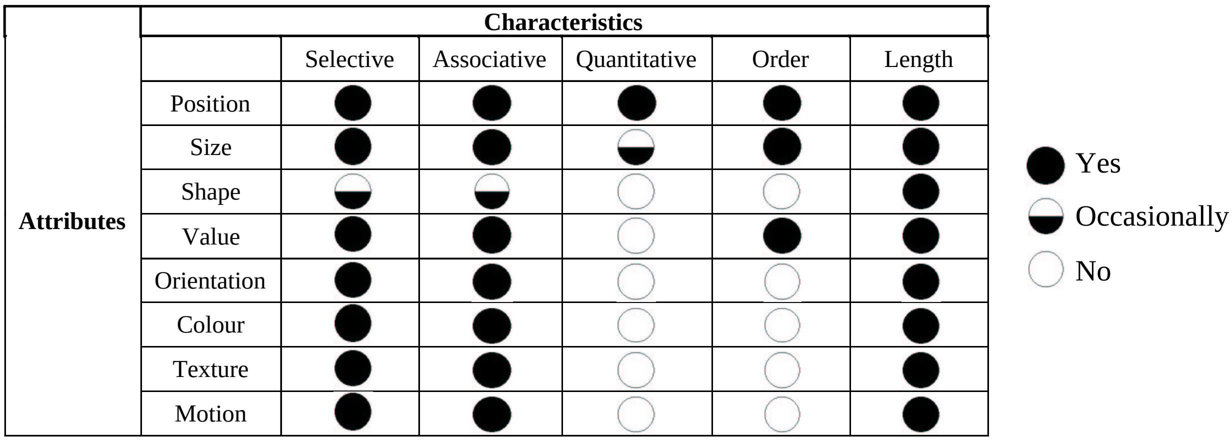

Figure 2. Grid relating which visual variables exhibit which characteristics

The basic structures for displaying data are the sentence, table, and the graphic. Often one should combine these to produce an outcome that is rich in information. Combining words, numbers and pictures often reveals a lot about the data, giving an explanation of the data to the viewer. This explanation allows the user to be at ease with the content of the graphic as apposed to an overwhelmed feeling of the data trying to be displayed. Placement of these labels should be on the plotting field at interesting data points. Equations could also be displayed and sometimes a table might even be added to the graphic itself [Tufte 1999b].

The text should be kept small, as it will not be very lengthy. This will not tire out viewers as it does with lengthy sentences of small text which hampers usability. The font should also be kept the same. Words, tables, and graphics all have the same purpose, the presentation of information [Tufte 1999b].

Confusion and clutter are the products of bad design, not attributes of information. Layering and separation can solve this, but is difficult to do effectively. Often layering and use of separation can complicate a graph resulting in non-information patterns. However, providing a subtle difference in colour for different elements on the graph can really add to the clarity of the information being displayed [Tufte 1999a].

Emotion is something that everyone has, and no two people are the same in this regard. There are however common behaviors amongst us, whether it be that certain colours spark a common emotion within ourselves, or that a cluttered interface makes us feel uneasy. Keeping the above or a combination of the above guidelines in mind when creating graphs will help you present data that is clearer to the viewer, both visually and emotionally and thus provide more value and meaning.

4. INTERACTIVITY IN GRAPHS

Creating graphics to display large datasets provides us with very valuable information, information that might have gone unnoticed otherwise [Kaufman 2000]. When large amounts of data are displayed in a graphic it can however cause confusion. Introducing interactivity to the graphic has been shown to improve its effectiveness [Kennedy et al. 1996]. This effectiveness shows in the intuitiveness that interactivity provides to the graphic [Koop 1995]. Interactivity can take on various different forms. Allowing the user to change visual variables such as colour is a form of interaction, querying the data and the exploration of data are yet other ways of being interactive [Domik 1999]. Graphics should display an overview of the information first, giving the option to zoom and filter, thus allowing the user to get the details-on-demand [Shneiderman 1996].

4.1 Overview

When viewing a graphic for the first time, it should provide an overview of the data [Stolte et al. 2002]. The purpose of the graphic should be conveyed so as not to give the user the wrong impression of what information is being displayed while in this zoomed out view [Shneiderman 1996]. This view shows a summary of the data, but the graphic should still encourage exploration [North 2001].

4.2 Zooming and Filtering

Users will find certain areas of the graphic interesting and will want to zoom in on them [Shneiderman 1996]. One of the goals of interaction is separating interesting areas from those that are of less interest to the users, thus allowing them to get more detail about that area [Sahling 2002]. This can be accomplished in many ways.

Closely related to the concept of zooming is that of filtering out the data that is not of interest. This sought of functionality is provided by performing queries on the data to extract the information needed, this is one of the key ideas of information visualization [Shneiderman 1996].

4.3 Details-on-demand

Once the target area of interest has been reached, the process to view the details of a point on a graph or a value pertaining to a visual variable should be straightforward. These values could display on a popup after clicking on a point [Shneiderman 1996].

Principles such as continuous interactivity, real-time response and direct manipulation of lines and curves can provide the user with an environment that that is a lot more enjoyable [Shafrir and Smith 1997]. This is definitely the case with direct manipulation where interaction with graph elements gives immediate response, as well as allowing the user to undo changes easily [North 2001]. This ability to manipulate the graphic at will gives the control back to the user and by doing this provides the user with an environment that is less stressful to work in as changes to the visual can be easily reversed [Wilhelm 2002].

Interactivity gives graphics that already provide invaluable information, endless possibilities to how much detail can be displayed as well as the option to change the physical properties of the graph such as the colour of certain values. This type of functionality is very sought after, but also comes at the price of speed of performance and cost of development. These kind of issues have to be examined when building interactivity into graphs.

5. BUILDING INTERACTIVITY INTO GRAPHS

Interactivity introduces to a static graph a whole new element of valuable and interesting features. With the advent and growth of information technology, a whole new array of functionality became possible. Where before, someone would be seen as the viewer of a graph, they now become the user. The user can now control the sequence, the pace, as well as what they want to see or wish to ignore [Kristof and Satran 1995].

Building interaction into graphs does not only mean defining what happens on each individual graph, but is rather a combination of how the user gets to that point of interest, the actions performed while they are there, as well as how they leave that area. All these aspects of interaction should be well integrated, as to provide an experience that encourages exploration and does not make the user feel awkward in the environment presented to them [Kristof and Satran 1995].

Interactivity can be implemented in a number of ways using a number of different technologies. Some of these interactive functions for graph manipulation work better in certain graphics than in others. One could use sliders, which are provided in many dynamic software packages, to change the value of a parameter in an equation or how objects on the graphic behave [Shafrir and Smith 1997]. By moving the slider with a pointing device, you would be changing a corresponding value in the equation and therefore also changing the way the graph is plotted. This sort of interactivity is very useful for the education of students when it comes to seeing the effect of changing the variables in an equation. It answers the students “What If?” questions. It can however present some ambiguity in certain situations and should therefore not be used in every situation. This may be the case when multiple equations are being manipulated by the slider, or when the equations and corresponding graphs are complex. The decision to incorporate this feature into the graphic should be left up to the creator of the graph [Dye 2002].

Where sliders support what-if scenarios, region selection helps users identify areas that are of interest to them. The selection of meaningful regions of an image produced from volumes of data can provide the user with information that is important to them, especially when the graphic is being used for analysis purposes [Stoev and Straßer 2000]. Building features such as region selection into your graphic provides the user with an attractive environment. This gives the user a feeling of control as they can select whatever they please. This is important as the benefit gained from providing the graphic with meaning from the visual variables used should not be hindered by the way interactivity is implemented into the graphic but should rather supplement this experience. Region selection is used to gain information about a selected item or area. This is commonly used in cartography where a region on a map needs to be explored in further detail. This kind of detail can be displayed as textual information or emphasis can be placed on that area by zooming in on it [Shneiderman 1996].

Industry is looking for systems that allow zooming and drilling down into graphics to get more detail on a section [Currid 2001]. The amount of information being kept in storage is ever increasing with today's storage devices being able to hold massive amounts of data. Zooming-based techniques allow users to easily zoom in on any part of the display to reveal the next level of detail. This then allows the user to get to the information that is sought after [Masui et al. 1995]. Zooming can be implemented on a dimension at a time by allowing the user to move a zoombar control or by adjusting the size in a field-of-view box. A very intuitive way of controlling the zoom is by allowing the user to point at a location on the graphic and then let them issue a zooming command. This command is normally controlled by clicking a mouse button on the point of interest [Shneiderman 1996].

After presenting the viewer with an overview of the information and then allowing the user to zoom and filter the data, they can then click on points on the graph to get details-on-demand. The usual approach is to click on an item at which time a popup appears with values relative to that specific point [Shneiderman 1996]. Direct manipulation allows the user to click on graph elements such as lines and curves and retrieve information about the selection [Shafrir and Smith 1997]. It provides functionality to make changes that are rapid as well as being reversible, and also focuses on providing continues and immediate feedback [North 2001].

There are countless tools that have been and are currently being developed to allow people to interrogate graphs so as to probe some added information out of them. The discussion here has been on visual interactivity, however there are other ways of building interactivity into graphs. Software engineers and those involved in human-computer interaction are striving to make computer systems as intuitive as possible. This has opened up a whole new dimension of interaction that is sound. This would allow the user to interact with a graphic using speech. These audio and other technologies such as virtual reality allow the user to perform the utmost amount of interactivity with the system [Masui et al. 1995]. These technologies however are not available to most of us, as they either cost too much to purchase and train people to use and develop interactive packages in them, or because they require powerful systems to operate on. This is especially the case in the area of graphic manipulation where quick response time is of utmost importance and where detail can generally not be compromised.

6. CONCLUSION

Visualizing data is difficult, putting those ideas on paper can be even more difficult. The problem is that the benefits of information visualization are clouded by the way in which graphics are created.

This paper has discussed how keeping the core variables or visual variables in mind when constructing graphics, and following certain guidelines can produce graphics that convey the meaning intended. These visual variables have meaning attached to them and this meaning can either make your visual incredibly descriptive of misleading and confusing. Making use of the characteristics of visual variables will also prove to add to the success of the graphic.

Interactivity was also discussed which can solve many of the problems related to allowing the user to decide which areas are of interest to them. Keeping in mind the principle of providing an overview first, then allowing the user to zoom and filter, and finally getting details-on-demand will ensure that your graphics are intuitive and usable.

Which guidelines apply to a certain situation is left up to the user. No two graphics are the same, whether that be because of how they are drawn or who is interpreting them. This is not a silver bullet to all your graphical complaints and mishaps, but if followed correctly can prove to help produce graphics that will become an invaluable part of the information being visualized.

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