The History of Schematics in Data Visualization

Sheila Pontis
sheilapontis@gmail.com
October 2007

Abstract:
This article explores the topic of schematics as an essential tool in data visualization. To understand the complex world of data visualization, the first step must be to learn about the history and evolution of graphics, always closely linked to breakthroughs in theoretical knowledge and technological developments. Socio-cultural influences on its development will also be examined.

Key words:
Schematics, history, visualization, data, design, technology.

1. Introduction

The role of images in the transmission of knowledge has gained prominence over the last forty years. This is due to illustrators' capacity to express themselves graphically, developments in printing, and users ability to understand graphic information[1] and relate images to reality.
Visual language[2], irrespective of its characteristics, transmits a two-dimensional message. When the eye contemplates an image, it wanders freely over the optical surface of the image. And even in cases where the eye is not free, such as a set of graphic instructions, it thinks it is and wanders as it will; it is not disciplined by a mechanism of cultural obligation (learning to read) which forces the eye to move along a line[3].

Written messages require linear thought , while visual messages lead to surface thought [4]. Yves Deforge presented this concept in his book, Imagen Didáctica stating that the two forms of thought have competed- and complemented each other- throughout history. Beyond the written word, sets of techniques have evolved to transmit data, knowledge and information in such a way that the relationship among the parts of the whole is understood. This set of techniques, a part of visual language, comprises functional images, including diagrams and maps.
Schematic language is the name of the visual language of surfaces that has evolved in tandem to written linear language and aims primarily to make information visible. This study will explore the beginnings and evolution of data visualization, closely linked to breakthroughs in theoretical knowledge and technological developments. Socio-cultural influences over the course of its development will also be highlighted.

2. A history of schematic graphics to the present day

This historical overview will begin with a quote from Professor Justo Villafañe of the Universidad Computense de Madrid. He considers that, since its origins, schematic

[1] Abraham Moles defines **graphics** as the result of the combination of iconic, sign, linguistic and chromatic elements applied for diverse purposes in the varied field of design. Moles, Abraham. *Imagen Didáctica,* Editorial CEAC. Barcelona, 1991. p. 42.

[2] In this investigation, visual language is defined as one using images and graphic elements to communicate concepts.

[3]. *Op. cit.* 1. p.10.

[4]. *Op. cit.* 1. p.207

language has evolved through a constant process of trial and error [5], which he explains as the need to create a new way of representing reality that corrects some key factor in the previous model. The constant need to change graphic representation arises as images are used for new purposes. The trial and error" process, like a cyclical path, runs throughout the history -and future- of visual representation. Historical periods have each had their own needs, for which they have generated their own graphic representation methods to reproduce reality.

Like Philip Meggs, Villafañe begins his analysis with the Egyptian culture[6], which is characterized by imposing a frontal view of life and can be considered the first manifestation of an attempt at representing reality.
Classical Greek culture, the protagonist of the second great era, offered a new way of "equalizing" and correcting the previous system[7].
Chronologically, the next important correction that Villafañe describes took place in the 15th and 16th centuries during the artistic movement of the Renaissance. This movement produced a change in the way the world and human beings were understood, replacing the Theo-centrism that had characterized the Medieval Period with the anthropocentric view of the Renaissance. The artistic style of Naturalism that developed mid-19th century is also seen by Villafañe as an accumulation of corrections arising from the observation of surrounding reality.

Babylonian maps on clay tablets, created approximately 4500 years ago, were considered the oldest maps in existence until 1963, when archaeologist James Mellaart (1925-) discovered a map in Ankara, Turkey, from 6200 years BCE (Before the Common Era). The first map of the world was also created in Turkey, as far as we know, about 550 BCE, by Anaximander (610 BCE 546 BCE). This map is a simple illustration where the world is synthesized in a circle, containing three continents: Asia, Europe and Africa[8].
Dating from about 366 BCE is the first route map[9] (carte routière), representing the road system of the Roman Empire. It was discovered in 1494 by the German Konrad Peutinger (1465-1547).
Geographer Claudius Ptolemy (90 CE-160 CE) also made a map in the year 150 CE (Common Era), which was one of the first to use the coordinate principle for map-making.
In ancient times, the Egyptians developed papyrus for writing their manuscripts, a major breakthrough in visual communication. In 170 CE, parchment was invented, a material that enhanced the creation of visual images because it made it possible to create images on both sides (front and back), the main characteristic that distinguishes it from papyrus.
In 105 CE, in China, Ts ai Lun (50 CE 121 CE) created paper, replacing inscriptions on wood, cloth or stone. The process for making paper remained unchanged until its production was mechanized in 19th century England.

The first known examples of data visualization are geometric diagrams, charting the positions of the stars and other heavenly bodies, and maps to aid navigation and exploration.
In his book *Historical Development of the Graphical Representation of Statistical Data*, Funkhouser identifies what he considers the first graphic construction, circa 950 CE. This image, discovered in 1877 by the German Sigmund

5. Villafañe Gallego, Justo. *Fundamentos metodológicos de la teoría de la imagen (referidos a la imagen fija)*. Doctoral thesis. Editorial de la Universidad Complutense de Madrid, 1981. Madrid. p.282

6 The first Egyptian manifestations date approximately from the year 5300 BCE.

7. *Op. cit.* 5. p.289

8. Buisseret, David. *La revolución cartográfica en Europa, 1400-1800*. Ediciones Paidós Ibérica, S.A. Barcelona, 2003. p.20

9. *Op. cit.* 8. p.34

Günther, was part of a manuscript kept at the *Bayerische Staats-Bibliothek* in Munich. It was structured in squares and accompanied a description of planetary movements through the zodiac over time.

However, other authors, such as Paul Mijksenaar (1944-), consider the work of Nicole Oresme (1323-1382) to be the first graphic representation of data.

In 1375 a world atlas was made known as the Most complete atlas of visual geographical knowledge of the late Middle Ages . This book was a complete visual work of cosmography, along with a perpetual calendar and a thematic representation of the known world. The Atlas was commissioned by Charles the Fifth of France (1338-1380) and made by Catalonian Abraham Cresques (?-1387)[10].

The graphic representations up to the mid-14th century mentioned in this historical overview reflect humans knowledge of the world at that time, which was not based on scientific or theoretical explanations. This information can be summarized in the concept of mimesis, which consists of the expression of our "knowledge" of nature and the world we live in. This type of graphic representation did not yet reflect any pre-established codes, given that a code is a set of systematic norms regulating a given subject as a whole. The concept of mimesis is close to aesthetic reproduction; in contrast, the concept of codes is related to pre-established rules and parameters.

A major advance in the history of visual language was the possibility of reproducing visual representations in a way that was not manual. The first great invention in reproduction techniques came from China, with the creation of relief prints (wood-engraving). Meggs considers that this invention may date from the year 165 CE. A further development in relief printing was that of movable type, about the year 1045, thanks to the Chinese alchemist Pi Sheng (1022-1063), who made the type out of a mixture of clay and glue. In 1453, it became possible to make prints through the use of independent, movable and reusable pieces of metal, each of which had the shape of a letter on the top [11]. This technique (typographical printing), created by German Johann Gutenberg (1398-1468), made it possible for knowledge to spread quickly through the massive production of copies, which in turn led to increased levels of literacy and allowed text and image to merge on the same page.

In the 16th century, techniques and instruments were created for more accurate observation and measurement of physical quantities. These steps comprise the beginnings of the discipline of visual representation.

2.1 17th Century: Measurement and theory

The principle concerns of the 17th century were the physical measurement of time, distance and space, in making maps for navigation and territorial expansion purposes. Objects were created that enabled greater accuracy in technical illustrations and enhanced the reproduction of figures on different scales.

In 1626, Christopher Scheiner (1575-1650) produced a visual sequence that represented changes in sun spots over time, developing one of the principal contemporary tools for information visualization: *Small Multiple*.

Analytical geometry, begun by Descartes (1596-1650) in 1637, helped to determine how to represent the curve of an equation

[10]. Friendly, Michael. Denis, Daniel J. *Milestones in the History of Thematic Cartography, Statistical Graphics, and Data Visualization*. York University, Canada.

[11]. Meggs, Philip B. Historia del diseño gráfico. McGraw-Hill/Interamericana Editores, S.A. México, 1998. p.58

graphically, determining the relationship between the coordinates of each point of the curve, which contributed a new methodology to graphic data visualization[12].

Major breakthroughs in the body of theoretical knowledge (probability theory and demographic and political statistics) also took place in the 1600s as scientific theories were put into practice, leading to the first constructions of tables and graphs and the systematic gathering of statistical data.

The combination of cartography and statistical abilities produced data maps[13]. The first data map, made by Englishman Edmond Halley (1656-1742) in 1686, was created to reflect weather patterns, showing wind forecasts on a geographic map.

At the end of the century, the necessary elements for the development of graphic constructions had been introduced. During the 17th century, the ingredients needed to form the discipline of visual thought were procured[14].

2.2 18th century: new graphic forms

During the 18th century, the initial creations related to data visualization developed in prior years were enhanced and diversified. Mapmakers began to attempt to show more than geographical positions, which resulted in new graphic typologies. Along with the beginnings of statistical theory and the systematic gathering of empirical data, abstract graphics and function graphics were introduced. Technological innovations such as colour printing and lithography generated the raw material that enabled the reproduction and creation of images of data. At first, many of these graphic forms appeared in publications with limited circulation, and therefore were not widely known.

Maps were among the graphic constructions that evolved most. Different types of maps were created to represent specific needs, such as contour maps, chronological maps (1753) and geological maps (1775). The development of descriptive geometry in 1776, known as the Monge (1746-1818) system contributed greatly to the representation of three-dimensional reality on two-dimensional paper.

Priestley and Playfair

Funkhouser considers Joseph Priestley (1733-1804) the creator of statistical graphics, while Edward Tufte believes they were invented by Johann Heinrich Lambert and William Playfair (1759-1823)[15]. Historically, the first

12 Funkhouser, H. G. *Historical Development of the Graphical Representation of Statistical Data*. Osiris, Vol. 3. 1937, pp. 273-320, p. 277.

13. "Data-map". Tufte, Edward. Beautiful Evidence, Graphic Press. Cheshire, Connecticut, USA. 2006. p.20.

14 In this investigation, the concept of **visual thought** is used as a way to describe visual language. In other words, visual language, as opposed to textual language, is structured on the base of images and therefore, the reader can link and relate ideas and concepts. Thus, this type of reading is similar to a way of thinking. Thought can be defined as a succession of images with no apparent pre-established order. In this same way, schematic language is constructed. Although it is structured, it is not a rigid language permitting only one type of reading.

To offer a better description of this concept, we will quote some of Rudolf Arnheim's words. He divided visual thought into intuitive thought and intellectual thought. These concepts are related to those described by Deforge in the previous chapter. In other words, Deforge (like Meggs) considers textual language as a typology of visual language, describing both languages as forms of thought: linear and superficial, respectively. If we return to Arnheim's denominations, a conceptual parallel may be drawn.

Intuitive thought takes place in a perceptual force field that act freely (a surface). The components of the field exert a perceptual effect on each other such that the observer perceives several individual components that are related to one another, which form the image as a whole. The final result is perceived as an organization of forms and colours whose specific character is determined by their place and function in the whole. Intuitive thought is also called synoptic thought by Arnheim.

Arnheim describes **intellectual thought** as one comprising components that interact with each other in a linear succession (linear thought). Based on fairly stable components that interact within a perceptual field, stable and independent concepts are developed. Some representative examples of intellectual thought are the linking of concepts in verbal sequences, the sum of factors. In sum, the term visual thought is used to include both these concepts, placing special emphasis on intuitive or surface thought. Arnheim, Rudolf. *El pensamiento visual*. Edición Paidós Ibérica, Barcelona, 1998. pp. 246-247.

15. William Playfair was a political economist and engineer who made significant innovations in the field of data representation. He started as an apprentice to Andrés Meikle, the inventor of the threshing machine, and later worked as a draughtsman with James Watt.

Some authors consider him the creator of line graphs, bar graphs, and pie charts. His time-series graphics are still models of clarity. In 1786, he published his Commercial and Political Atlas in London, which contained 43

recorded case of time portrayed as a graphic line (*time-series*[16]) was in a publication by Priestley dated 1765.

The time-series published in 1786 in Playfair s Atlas, *The Commercial and Political Atlas* (London), in addition to the majority of its graphics, represented information about economics. Playfair s study was significant given that it marked the creation of a new graphic method[17] that offered an alternative to the tabular presentation of information used prior to that date. As Playfair said: Graphics are preferable to tables because graphics show data from a comparative perspective [18].

2.3 19th century: modern information graphics

Thanks to innovations in design and technical breakthroughs, the first half of the 19th century saw explosive growth in statistical graphics and thematic maps. All kinds of visual graphic forms were invented, such as bar graphs and pie charts, histograms, line graphs, time lines, contour maps (1843), isothermic graphs (1817), parabolic graphs, cartograms (1826), dot-maps (1830), transport maps (1837), and combined graphs.

Demographic and statistical analyses (known as moral statistics: crimes, suicides, literature) began to be presented graphically in tables, diagrams and thematic maps. André Michel Guerry (1802-1866) is considered the founder of moral statistics analysis, in subjects such as criminology, sociology and social sciences.

About 1835, mathematician, statistician and sociologist Lambert Adolphe Jacques Quételet (1796-1874) was the first to apply statistical methods in the social sciences, using statistical laws to explain behaviour patterns in crimes, weddings and suicides.

Also worthy of mention is French engineer Charles Joseph Minard (1781-1870), who added statistical diagrams and bar graphs to cartographic maps. According to Tufte, "It may well be the best statistical graphic ever drawn".[19]. This graph, made in 1861, was published in a collection of his works and represents the terrible fate of Napoleon's army in Russia.

First conferences on graphic methods

In the 19th century, two data visualization methodologies were used. One supported tabular charts, and the other began to discover the benefits of graphic methods of visual representation. The first step in the growth of visual data representation took place in Europe with the establishment of official offices of statistics. This was proof of the recognition of the growing significance of statistical information for social planning, industrialization, commerce and transport. Moreover, between 1830 and 1850, there was a growing interest in carrying out studies about statistical data. Numerous statistical companies and agencies were established and municipal statistics were created in several countries. Public interest also increased in the results of research into the development of the statistical

---

time-series and a bar graph, a graphic form that he apparently invented. It was described as the largest work containing statistical graphics. In addition, Playfair made a comparison between his “new” graphic method and the “old” tabular method for presenting information. He considered graphs preferable to tables given that graphs show the “form” of the information in a comparative setting. *Op. cit.* 12. pp. 280-290

16. *Time-series* is the term Tufte used to describe the graphic typology of a time line. *Op. cit.* 13. p.28

17. **Graphic method** refers to the form of representing information and data through the use of graphic constructions made with interrelated graphic elements, with a visual complexity that is more communicative than tabular charts. It is the organization and representation of information with visual language.

18. “*The advantage proposed, by this method, is not that of giving a more accurate statement than by figures, but it is to give a more simple and permanent idea of the gradual progress and comparative amounts, at different periods, by presenting to the eye a figure, the proportions of which correspond with the amount of the sums intended to be expressed*”. *Op. cit.* 12. p.281

19. *Op. cit.* 13. p.25

graphics method. These joint analyses led to the creation of the International Conference on Statistics. The first congress was held in Brussels in 1853, followed by eight more: Paris 1855, Vienna 1857, London 1860, Berlin 1863, Florence 1867, The Hague 1869, Saint Petersburg 1872, and Budapest 1876.

The golden years for graphic methods

The years from 1860 to 1890 were very important in the consolidation of the graphic method, and could be called the golden years of the graphic method. Anyone with imagination who was able to make visual representations based on information began to experiment with the new language. The graphic method was officially recognized by governmental agencies and accepted in publications as a standard information source. Different typologies for visual representations began to be incorporated into publications.

2.4 20th century: a time of changes

The early 20th century was a time of changes in social, political, cultural, and economic life that radically altered several aspects of the human condition. World War I (1914-1919) mobilized Western civilization, bringing about a change in society's view of life. In this context, "graphic forms of communication underwent a series of creative revolutions that questioned their values, their approach to the organization of space and their role in society [20].

That is why the early 20th century can be referred to as "the dark modern years" of visual data representation[21]. The initial enthusiasm about visual representation had been replaced by mass production of graphics that overemphasized aesthetics at the cost of content. This process intensified until graphic constructions were reduced to mere images. Though attractive and evocative, they could not represent a fact or transmit data accurately.

Society also reacted by applying and popularizing graphic methods to everything, and their use became standard in government and business, in addition to science. This stagnant period was a setback, characterized by the loss of technical precision.

Otto Neurath and Harry Beck

Developments in the graphic method included the creation of the language ISOTYPE (*International System of Typographic Picture Education*) in the 1930s in Vienna. This language of images combined rules from science and design in the construction of its visual signs and was developed by Otto Neurath (1882-1945). This system enabled the production of a large number of images that represented everyday words and concepts, and achieved a universal iconic language.

Henry C. Beck (1903-1974) introduced a new design in the London Metro system that constituted a new form of representing reality: map schematization. Despite the diversification of graphic typologies, map characteristics had not changed in 130 years. Transport maps, for example, showed transport routes on accurate maps of the area. Thanks to Beck, graphic representation in transportation began to emphasize understanding how to get to a certain destination, no longer focusing on the actual geographic characteristics of the area. A map where geographic features are almost totally absent, replaced by a more abstract representation of reality, is called a street map. From this point on, graphic constructions in transportation reflected the route, without identifying the topography.[22].

[20]. *Op. cit.* 11. p.231

[21]. *Op. cit.* 10.

[22]. Ovenden, Mark. *Metro Maps of the World.* Capital Transport. CS

With time, the concept of abstraction and geometrization began to be applied to various schematic typologies.

2.4.3 New technologies: information science

During the 20th century, new ideas and technological development made it possible to explore the representational potential of two dimensional maps. New methods enabled three-dimensional information representation, which fostered the development of multi-variable graphics. Large U.S. corporations filled an important role in the development of products and services, which brought information design out of a sluggish period. The invention of the first computer in 1944[23] made it possible to test and experiment with various graphic techniques for making diagrams and maps. Information technology also led to new uncertainties, which motivated a return to studies related to graphic methods.

In France, Jacques Bertin (1918-) published *Semiologie Graphique* (1963), which became the essential book for organizing visual and perceptual elements in accordance with information characteristics and relations. Bertin s work created the foundations of the principles of graphic semiotics, developing a theory of graphic symbols and representational modes.

In the U.S., John W. Tukey (1915-2000), in his publication *The Future of Data Analysis*, called for the recognition of data analysis as a legitimate branch of statistics, separate from mathematical statistics. These breakthroughs in graphics, published in 1977, meant that data graphics began to garner respect and serious interest once again.

Computers offered the possibility of constructing new and old graphic forms with specialized software. High-resolution graphics were developed, although some years passed before the use of information technology became widespread.

In 1974, Jerome H. Friedman and Tukey began interactive graphic statistics (the PRIM-9 system), also in three dimensions.

Toward the end of this period, the full potential of technology was unleashed. Scientific research by computer was developed and software tools were produced, as well as specific languages (C, UNIX), breakthroughs in data analysis, exhibitors and reproduction techniques (*plotters*, graphic terminals, graphics tablets, the mouse, etc.). These advances in techniques and metholodologies for work enriched graphic constructions and mechanized their development, while generating new paradigms. New challenges arose: visual representations of multivariable information, animations of statistical processes, and theories based on perception, related to finding ways to improve communication and understanding between the reader and the data.

3. Conclusions

Currently, the structure of the organization and visualization of information is changing very quickly, becoming more complex every day. This is mainly due to the participation of a wide range of disciplines in the stages of the process of "translating" data: selection, simplification, communication, synthesis, graphic universality. In technological circles, a variety of interactive information systems and new tools have been

Graphics, Singapore. 2005. p.9

23 In 1944 the first digital computer started to operate, Harvard's Mark I, officially known as "IBM Automatic Sequence Controlled Calculator'' (ASCC). It was 50 feet long and weighed almost 5 tonnes. It was developed in the United States by Howard H. Aiken (1900-1973) and Grace Hopper (1906-1992).

created for the direct manipulation of visual data analysis, which are making it possible to generate various techniques for constructing an infinity of graphic forms of data visualization.

In conclusion, breakthroughs in visual data representation techniques and methods are closely linked to technological development and an increasing body of theoretical knowledge. Thanks to the combination of these advances and theories, solutions are currently being found for some of the problems mentioned throughout this historical overview, such as the lack of graphic resources, the search for a universal graphic language, delays in creation times, and graphic constructions that communicated information poorly.

Software programs are a practically inexhaustible source of graphic resources that make it possible to constantly renew the raw material of graphic constructions and to develop new structures. The development of the World Wide Web has enabled data transmission and the communication of elements, opening the way for universal graphic resources. Working with computers has reduced the time needed to create graphic constructions, making more time available to improve their communicative quality and to find the most appropriate graphic technique.

The application of graphic data representation methods to various information problems is constantly expanding, and we must remember that the main purpose of all graphic constructions is communication.

4. Bibliography

"Arnheim, Rudolf. *Arte y percepción visual. Psicología de la visión creadora.* Ed. EUDEBA. Bs. As. Argentina, 1962

"Arnheim, Rudolf. *El pensamiento visual*. Edición Paidós Ibérica, Barcelona, 1998.

"Bertin, Jacques. *Semiology of Graphics. Diagrams, Networks, Maps*. The University of Wisconsin Press, USA. 1983

"Buisseret, David. *La revolución cartográfica en Europa, 1400-1800*. Ediciones Paidós Ibérica, S.A. Barcelona, 2003

"Friendly, Michael. Denis, Daniel J. *Milestones in the History of Thematic Cartography, Statistical Graphics, and Data Visualization*. York University, Canada.

"Funkhouser, H. G. *Historical Development of the Graphical Representation of Statistical Data*. Osiris, Vol. 3. 1937, P. 272-464

"Holmes, Nigel. *Lo mejor en gráfica diagramática*. Mies (Suïssa), Rotovisión, 1993

"Meggs, Philip B. *Historia del diseño gráfico*. McGraw-Hill/Interamericana Editores, S.A. México. 1998

"Mijksenaar, Paul. *Una introducción al Diseño de la información*. Ediciones GG. Barcelona, 1997

"Moles, Abraham. Costa, Joan. *Grafismo Funcional*. Editorial CEAC, Barcelona, 1990

"Moles, Abraham. Costa, Joan. *Imagen Didáctica*. Editorial CEAC. Barcelona, 1991

"Monkhouse,F.J., Wilkinson,H.R. *Mapas y diagramas. Técnicas de elaboración y trazado*. Oikos-tau, S.A. Ediciones. Barcelona, 1963

"Neurath, Otto. *International Picture Language. The First Rules of Isotypes*. London, R.L. Severs, Cambridge, 1936

"Ovenden, Mark. *Metro Maps of the World*. Capital Transport. CS Graphics, Singapore. 2005

"Tufte, Edward. *Beautiful Evidence*. Graphic Press. Cheshire, Connecticut. USA. 2006

"Tufte, Edward. *Envisioning Information*. Graphic Press. Cheshire, Connecticut. USA. 1990

"Tufte, Edward. *The Visual Display of Quantitative Information.* Graphic Press. Cheshire, Connecticut. USA. 1983

"Tufte, Edward. *Visual Explanations*. Graphic Press, USA. 1998

"Villafañe Gallego, Justo. *Fundamentos metodológicos de la teoría de la imagen (referidos a la imagen fija)*. Doctoral thesis. Editorial de la Universidad Complutense de Madrid, 1981. Madrid