Lev Manovich

What is Visualization?

Over the last 20 years, information visualization became a common tool in science and also a growing presence in the arts and culture at large. However, the use of visualization in cultural research is still in its infancy. Based on the work in the analysis of video games, cinema, TV, animation, Manga and other media carried out in Software Studies Initiative at University of California, San Diego over last two years, a number of visualization techniques and methods particularly useful for cultural and media research are presented.

I first drew the Chart in order to clear up my own ideas on the subject, finding it very troublesome to retain a distinct notion of the changes that had taken place. I found it answer the purpose beyond my expectation, by bringing into one view the result of details that are dispersed over a very wide and intricate field of universal history; facts sometimes connected with each other, sometimes not, and always requiring reflection each time they were referred to. (William Playfair, *An Inquiry into the Permanent Causes of the Decline and Fall of Powerful and Wealthy Nations* (1805) *[in reference to "The Chart, No. 1, representing the rise and fall of all nations or countries, that have been particularly distinguished for wealth or power, is the first of the sort that ever was engraved, and has, therefore, not yet met with public approbation."]*)

The pretty photographs we and other tourists made in Las Vegas are not enough. How do you distort these to draw a meaning for a designer? How do you differentiate on a plan between form that is to be specifically built as shown and that which is, within

in: *DIGAREC Keynote-Lectures 2009/10*, ed. by Stephan Günzel, Michael Liebe, and Dieter Mersch, Potsdam: University Press 2011, 116-156.
http://pub.ub.uni-potsdam.de/volltexte/2011/49849/ [urn:nbn:de:kobv:517-opus-49849]

> constraints, allowed to happen? How do you represent the Strip as perceived by Mr. A. rather than as a piece of geometry? How do you show quality of light – or qualities of form – in a plan at 1 inch to 100 feet? How do you show fluxes and flows, or seasonal variation, or change with time? (Robert Venturi, Stefan Izenour, and Denise Scott Brown, *Learning from Las Vegas* (1972))

> 'Whole' is now nothing more than a provisional visualization which can be modified and reversed at will, by moving back to the individual components, and then looking for yet other tools to regroup the same elements into alternative assemblages. (Bruno Latour, *Tarde's Idea of Quantification* (2010))

What is information visualization? Despite the growing popularity of infovis (a common abbreviation for "information visualization"), it is not so easy to come up with a definition which would work for all kinds of infovis projects being created today, and at the same would clearly separate it from other related fields such as scientific visualization and information design. So let us start with a provisional definition that we can modify later. Let's define infovis as a mapping of data to a visual representation. Of course, we can also use different concepts besides 'representation,' each bringing additional meaning. For example, if we believe that the brain uses a number of distinct representational and cognitive modalities, we can define infovis as a mapping from other cognitive modalities (such as mathematical and propositional) to an image modality.

My definition does not cover all aspects of information visualization – such as the distinctions between static, dynamic (i.e. animated) and interactive visualization – the latter, of course, being most important today. In fact, most definitions of infovis by computer science researchers equate it with the use of interactive computer-

see video recording of this *DIGAREC Keynote-Lecture* on:
http://info.ub.uni-potsdam.de/multimedia/show_projekt.php?projekt_id=79#79
[urn:nbn:de:kobv:517-mms-79-231-0]

driven visual representations and interfaces. Here are the examples of such definitions: "Information visualization (InfoVis) is the communication of abstract data through the use of interactive visual interfaces." (Keim et al. 2006) – "Information visualization utilizes computer graphics and interaction to assist humans in solving problems." (Purchase et al. 2008) If we accept this, our own definition also needs to include software tools that allow users to interact with and modify visual representations.

Interactive graphic interfaces in general, and interactive visualization in particular, bring all kinds of new techniques for manipulating data elements – from the ability to change how files are shown on the desktop in modern OS to multiple coordinated views available in some visualization-software such as Mondrian (www.theusrus.de/Mondrian/). However, regardless of whether you are looking at a visualization printed on paper or a dynamic arrangement of graphic elements on your computer screen which you generated using interactive software and which you can change at any moment, in both case the image you are working with is a result of mapping. So what is special about images such mapping produces? This is the focus of my article.

For some researchers, information visualization is distinct from scientific visualization in that the latter works with numerical data while the former focuses on non-numeric data such as text and networks of relations: "In contrast to scientific visualization, information visualization typically deals with nonnumeric, nonspatial, and high-dimensional data" (Chen 2005). Personally, I am not sure that this distinction reflects the actual practice – certainly, plenty of infovis projects use numbers as their primary data, but even when they focus on other data types they still rely on numbers to create visualizations. For instance, typical network visualization may use both the data about the structure of the network (which nodes are connected to each other) and the quantitative data about the strength of these connections (for example, how many messages are exchanged between members of a social network). As a concrete example, consider the well-known project *History Flow* (www.research.ibm.com/visual/projects/history_flow/), which shows how a given Wikipedia page grows over time as different authors contribute to it.

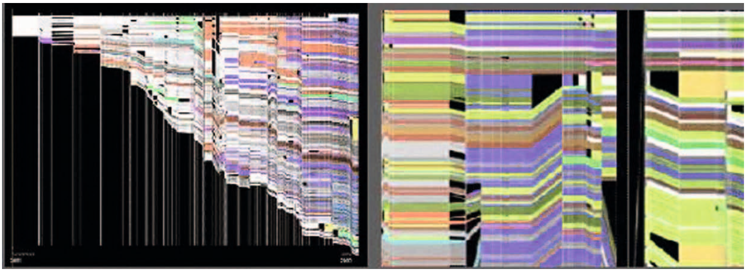

Fig. 1: History Flow by Fernanda B. Viégas and Martin Wattenberg, 2003 (Screenshot)

The contribution of each author is represented via a line. The width of the line changes over time reflecting the amount of text contributed by an author to the Wikipedia page. To take another infovis classic, *Flight Patterns* (www.aaronkoblin.com/work/flightpatterns/) uses the numerical data about the flight schedules and trajectories of all planes that fly over US to create an animated map which displays the pattern formed by their movement over a 24-hour period.

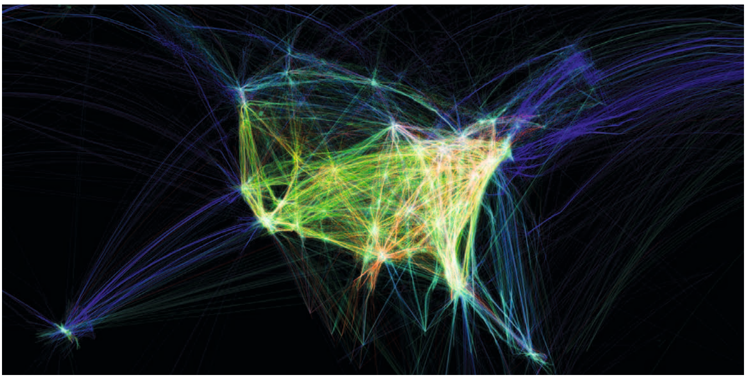

Fig. 2: Flight Patterns by Aaron Koblin, 2005 (www.aaronkoblin.com)

Rather than trying to separate information visualization and scientific visualization using some a priori idea, lets instead enter each phrase into Google image search and compare the results. The majority of images returned by searching for 'information visualization' is two dimensional and use vector graphics, i.e., points, lines, curves, and other simple geometric shapes. The majority of images returned by searching for 'scientific visualization' are three-dimensional; they use solid 3D-shapes or volumes made from 3D-points (called 'voxels'). The two fields therefore are indeed distinct on the level of visual techniques and technologies used. They also come from different cultures (science and design) and correspond to different areas of computer graphics technology. Scientific visualization developed in the 1980s along with the field of 3D-computer graphics, which at that time required specialized graphics workstations. Information visualization developed in the 1990s along with the rise of desktop 2D-graphics software and its adoption by designers; its popularity accelerated in the 2000s – the two major factors being the easy availability of big data sets via APIs provided by major social network services since 2005 and new high level programming languages specifically designed for graphics – *Processing* (processing.org) – and graphics software libraries – *Prefuse* (prefuse.org).

Can we differentiate information visualization from information design? This is trickier, but here is my way of doing it. Information design starts with the data that already has a clear structure, and its goal is to express this structure visually. For example, the famous London tube map designed in 1933 by Harry Beck starts with already organized data: tube lines, tube stations, and their locations over London geography.

Fig. 3: London Tube Map by Harry Beck (www.tfl.gov.uk/)

In contrast, the goal of information visualization is to discover the structure of a data set. This structure is not known a priori; visualization is successful if it reveals this structure. As is always the case with the actual cultural practice, it is easy to find examples that do not fit such a distinction – but a majority does. Therefore I believe that this distinction can be useful in allowing us to understand the practices of information visualization and information design as partially overlapping but ultimately different in terms of their functions.

Finally, what about the earlier practices of visual display of quantitative information in the 19th and 20th century that are known to many via the examples collected in the books by Edward Tufte (1983, 1990, 1997, 2006)? Do they constitute infovis as we understand it today? As I already noted, most definitions provided by the researchers working within Computer Science equate information visualization with the use of interactive computer graphics. (A number of definitions of information visualization from the recent literature is available at www.infovis-wiki.net/index.php?title=Information_Visualization.)

Using software, we can visualize much larger data sets than it was possible previously; create animated visualization; show how processes unfold in time; and, most importantly, manipulate visualizations interactively. These differences are very important – but for the purposes of this article, which is concerned with the visual language of infovis, they do not matter. When we switched from pencils to computers, this did not affect the core concept of visualization – mapping some properties of quantified data into visual dimensions. Similarly, while use of software led to the development of new visualization techniques, the basic visual language of infovis remains the same as it was in the 19th century – simple graphic primitives. Given this continuity, I will use the term "infovis" to refer to both earlier visual representations of data created manually and contemporary software-driven visualization.

Reduction and Spatiality

In my view, the practice of information visualization from its beginnings in the second part of the 18th century until today relied on two key principles. The first principle is reduction. Infovis uses graphical primitives such as points, strait lines, curves, and simple geometric shapes to stand in for objects and relations between them – regardless of whether these are people, their social relations, stock prices, income of nations, songs, or anything else. By using graphical primitives (or, to use the language of contemporary digital media, vector graphics), infovis aims to reveal patterns and structures in the sets of objects that these primitives represent. However, the price being paid for this power is extreme schematization. We throw away %99 of what is specific about each object to represent %1 – in the hope of revealing patterns shared by this %1 of objects' characteristics.

Information visualization is not unique in relying on such an extreme reduction of the world in order to gain new power over what is extracted from it. It came into its own in the first part of the 19th century, when in the course of just a few decades almost all contemporary graph types commonly found today in statistical and charting programs were invented. This development of the new techniques for visual reduction parallels the reductionist trajectory of modern science in the 19th century. Physics, chemistry, biology, linguistics, psychology and sociology proposed that both the natural and the social world should be understood in terms of simple elements (molecules, atoms, phonemes, just noticeable elements) and the rules of their interaction. This reductionism became the default "meta-paradigm" of modern science, and it continues to rule scientific research today. For instance, think of the popular paradigms of complexity and artificial life that focus our attention on how complex structures emerge out of interaction of simple elements.

Even more direct is the link between 19th century infovis and the rise of social statistics. Philip Ball (2004:64–65) summarizes the beginnings of statistics in this way:

> In 1749 the German scholar Gottfried Achenwall suggested that since this 'science' [the study of society by counting] dealt with the natural 'states' of society, it should be called Statistik. John Sinclair, a Scottish Presbutrian minister, liked the term well enough to introduce it into the English language in his epic Statistical Account of Scotland, the first of the 21 volumes of which appeared in 1791. The purveyors of this discipline were not mathematicians, however, nor barely 'scientists' either; they were tabulators of numbers, and they called themselves 'statists'.

In the first part of the 19th century, many scholars – Adolphe Quetelet, Florence Nightingale, Thomas Buckle, Francis Galton, and others – used statistics to look for 'laws of society.' This inevitably involved summarization and reduction – calculating the totals and averages of the collected numbers about the citizens' demographic characteristics, comparing the averages for different geographical regions, asking if they followed bell-shaped normal distribution, etc. It is therefore not surprising that many – if not most – graphical methods that are standard today were invented during this time for the purposes of representations of such summarized data. According to Michael Friendly and Daniel J. Denis (2009, Sec. 5), between 1800 and 1850:

> In statistical graphics, all of the modern forms of data display were invented: bar and pie charts, histograms, line graphs and time-series plots, contour plots, and so forth. In thematic cartography, mapping progressed from single maps to comprehensive atlases, depicting data on a wide variety of topics (economic, social, moral, medical, physical, etc.), and introduced a wide range of novel forms of symbolism.

Do all these different visualization techniques have something in common besides reduction? They all use spatial variables (position, size, shape, and more recently movement) to represent key differences in the data and reveal the most important patterns and relations. This is the second core principle of modern infovis practice at work for 300 years – from the very first line graphs (1711), bar charts (1786) and pie charts (1801) to their ubiquity today in all graphing software such as Excel, Numbers, Google Docs, OpenOffice, etc.

This principle means that spatial dimensions are privileged over other visual dimensions. That is, we map the dimension of our data set that we are most interested in onto the topology and geometry of the visualization elements. Other, less important properties of the objects are represented through different visual dimensions – tones, shading patterns, colors, or transparency of the graphical elements.

As the examples, consider two common graph types: a bar chart and a line graph. Both first appeared in William Playfair's Commercial and Political Atlas published in 1786 and became commonplace in the early 19th century. A bar chart represents the differences between data objects via rectangles that have the same width but different heights. A line graph represents changes in the data values over time via changing height of the line. In both cases, spatial relations are reserved for the key dimension of data we want to understand.

Now imagine making a scatter plot in order to understand relations in a large data set. If some objects cluster together, this implies that they have something in common; if you observe two distinct clusters, this implies that the objects fall into two different classes; and so on. Here as well, we use spatial variables (positions and distances between points) to make sense of the data.

Let us take another example – network visualizations which function today as distinct symbols of 'network society'. (See Manuel Lima's authoritative gallery visualcomplexity.com, which currently houses over 700 network visualization projects). Like a bar chart and a line graph, network visualizations also privilege spatial dimensions: position, size, and shape. Their main addition is the use of straight lines or curves to show connections between objects. For example, in Ben Fry's *distellamap* (benfry.com/distellamap), the lines connect pieces of code and data to show the dynamics of the software execution in Atari 2600 games.

Fig. 4: distellamap of ADVENTURE by Ben Fry, 2005 (benfry.com)

In Marcos Weskamp's *Flickr Graph* (marumushi.com/projects/flickr-graph) the lines visualize the social relationships between users of *flickr.com*.

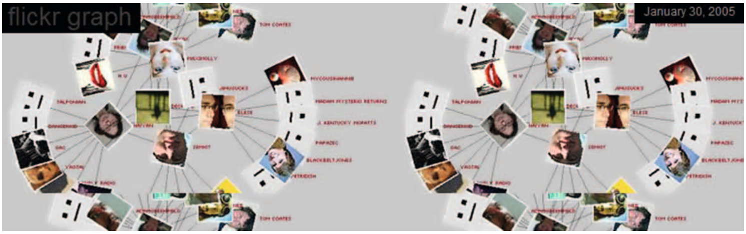

Fig. 5: Flickr Graph by Marcos Weskamp, 2005 (marumushi.com)

I believe that the majority of information visualization practices from the second part of the 18th century until today follow the same principle – reserving spatial arrangement (we can call it "layout") for the dimensions of the data that are most important for the authors of visualizations. This principle can be found in works ranging from famous dense graphic showing Napoleon's March on Moscow by Charles Joseph Minard to a recent The Evolution of 'The Origin of Species' by Stefanie Posavec and Greg McInerny.
(www.visualcomplexity.com/vc/project.cfm?id=696)

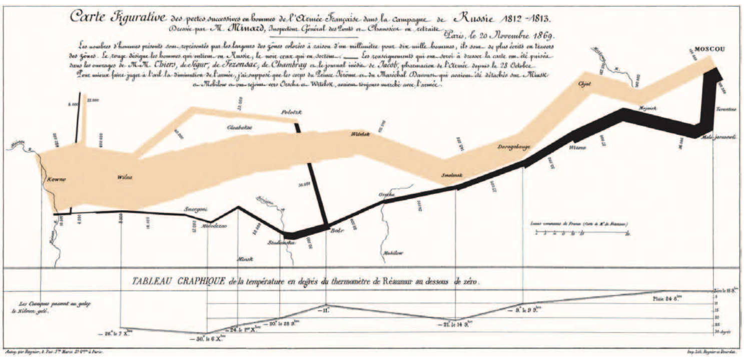

Fig. 6: Napoleon's March to Moscow 1812/13 by Charles J. Minard, 1869 (www.edwardtufte.com)

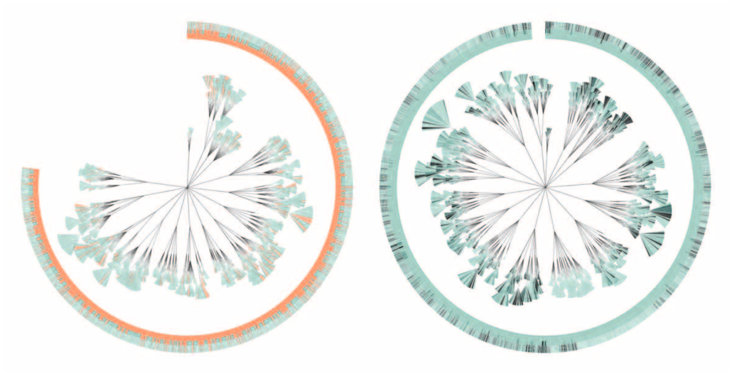

Fig. 7: The Evolution of 'The Origin of Species' by Stefanie Posavec and Greg McInerny, 2009 (www.visualcomplexity.com)

Spatial variables represent the most important dimension(s) of the data. Color is typically employed to identify graphical objects that belong to a particular group. In other words, it functions as a label. For example, Google Trends (www.google.com/trends) uses line graphs to compare the search volume of a few words or phrases.

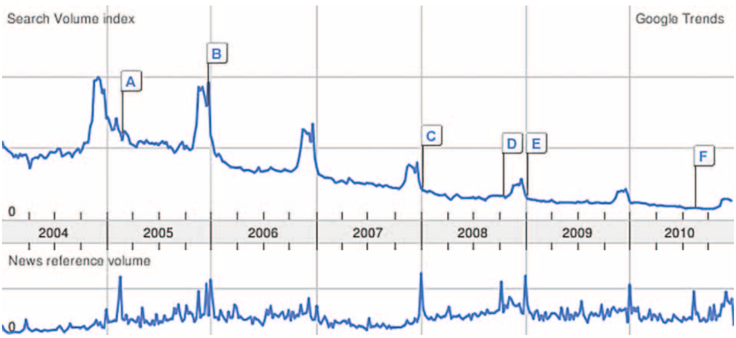

Fig. 8: "mp3 players"-Search by Google Trends, 2010 (www.google.com)

However, the same visualization could have simply used labels attached directly to the lines – without different colors. In this case, color ads readability but it does not add new information to the visualization.

The privileging of spatial over other visual dimensions was also true for plastic arts in Europe for a number of centuries: a painter first worked out the composition for a new work in many sketches; next, the composition was transferred to a canvas and shading was fully developed in monochrome; only after that was color added. This practice assumed that the meaning and emotional impact of an image depends most of all on the spatial arrangements of its parts, as opposed to colors, textures and other visual parameters. In classical Asian 'ink and wash painting', which first appeared in the 7th century in China and was later introduced to Korea and then Japan (14th century), color did not even appear. The painters used black ink exclusively, exploring the contrasts between objects' contours, their spatial arrangements, and different types of brushstrokes.

It is possible to find information visualizations where the main dimension is color – think, for instance, of a common traffic light which 'visualizes' the three possible behaviors of a car driver: stop, get ready, and go. This example demonstrates that we need to fix the spatial parameters of visualization in order for a color to become the salient dimension. Thus, it is crucial that the three lights have exactly the same shape and size. Apparently, if all elements of the visualization have the same values on spatial dimensions, our visual system can focus on the patterns represented by colors, or other visual variables.

Why do visualization designers – be they the inventors of graph and chart techniques at the end of the 18th and early 19th century, or millions of people who now use these graph types in their reports and presentations, or the authors of more experimental visualizations as featured on infoaesthetics.com and visualcomplexity.com – privilege spatial variables over other kinds of visual mappings? In other words, why are color, tone, transparency, and symbols used to represent secondary aspects of data while the spatial variables are reserved for the most important dimensions? Without going into the details of the rich but still very incomplete knowledge about vision accumulated by neuroscience and experimental psychology, we can still make a simple guess. The creators of visualizations follow human visual perception that also privileges spatial arrangements of parts of a scene over its other visual properties. Why would the geometric arrangement of elements in a scene be more important to human perception than other visual dimensions? We can assume that this has to do with the fact that each object occupies a unique part of the space. It is therefore crucial for a brain to be able to segment a 3D-world into spatially distinct objects which are likely to have distinct identities – people, sky, ground, cards, buildings, etc. Different object types can also often be identified with unique 2D-forms and arrangements of these shapes. A tree has a trunk and branches growing out of it; a human being has a head, a torso, arms and legs; etc. Therefore, identifying 2D-forms and their arrangements is also likely to play an important role in object recognition.

An artist or a designer may pay more attention to other visual properties of a scene such as textures and rhythms of color – but for most people, spatial properties are what matters most. How close are two people to each other; the expression on their faces; their relative size which allows the observer to estimate their distance from them; the characteristic shapes of different objects – all these and many other spatial characteristics which our brains instantly compute from the retinal input are crucial for our existence.

I think this is the reason why all standard techniques for making graphs and charts developed in the 18th–20th centuries use spatial dimensions to represent the key aspects of the data, and reserve other visual dimensions for less important aspects. However, we should also keep in mind the evolution of visual display technologies, which constrain what is possible at any given time. Only in the 1990s when people started using computers to design and present visualizations on the screen became color the norm. Color printing is still significantly more expensive – so even today science journals are printed in black and white. Thus, the extra costs associated with creating and printing color graphics throughout the history of visualization was probably an important factor responsible for the privileging of spatial variables.

When color, shading, and other non-spatial visual parameters were used in visualizations created in the 19^{th} and most of the 20^{th} century, they usually represented only a small number of discrete values – i.e. they acted as 'categorical variables.' However, today the fields of computer-based scientific visualization and geovisualization often use such parameters with much larger scales. For example, the common 24-bit format for color allows computers to represent 16 million different colors. Therefore in these fields, color, shading and transparency are now commonly employed to show continuously varying qualities such as temperature, gas density, gravity waves, etc. But does this not contradict my statement that spatial arrangement is a key to information visualization?

We can solve this puzzle if we take into account a fundamental difference between information visualization and scientific visualization or geovisualization, which I did not mentioned yet. Infovis uses arbitrary spatial arrangements of elements to represent the patterns in the data. Scientific and geovisualization typically work with an a priori fixed spatial layout of the real physical objects such as a brain, a coastline, a galaxy, etc. Since the layout in such visualizations is already fixed and can't be arbitrarily manipulated, color and/or other non-spatial parameters are used instead to show new information. A typical example of this strategy is a *heat map*, which uses color hue and saturation to overlay information over a spatial map.

The two key principles that I suggested – data reduction and the privileging of spatial variables – do not account for all possible visualizations produced during the last 300 years. However, they are sufficient to separate infovis (at least as it was commonly practiced until now) from other techniques and technologies for visual representation: drawing, painting, photography, video, film, radar, MRI, infrared spectroscopy, etc. They give infovis its unique identity – identifying its core, which remarkably remained the same for 300 years.

Visualization without Reduction

The meanings of the word 'visualize' include "make visible" and "make a mental image." This implies that until we 'visualize' something, this 'something' does not have a visual form. It becomes an image through a process of visualization.

If we survey the practice of infovis until the end of the 20th century, the idea that visualization takes data that is not visual and maps it into a visual domain indeed works quite well. However, it seems to no longer adequately describe certain new visualization techniques and projects developed since the middle of the 1990s. Although these techniques and projects are commonly discussed as "information visualization," it is possible that they actually represent something else – a fundamentally new development in the history of representational and epistemological technologies, or at least a new broad visualization method for which we don't yet have an adequate name. – Consider a technique called 'tag cloud.'

Fig. 9: Tag Cloud (manyeyes.alphaworks.ibm.com)

The technique was popularized by Flickr in 2005; besides its classical form used on numerous web pages today it also exists in new forms such as the Word Tree. In its standard version, a tag cloud shows the most common words in a text in the font size corresponding to their frequency in the text.

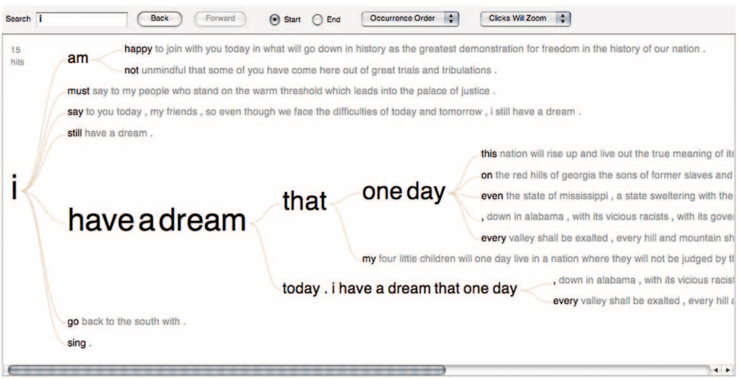

Fig. 10: Word Tree (manyeyes.alphaworks.ibm.com)

While we can use a bar chart with text labels to represent the same information, which in fact may work better if the frequencies are very similar, if the frequencies fall within a larger range, we don't have to map the data into a new visual representation such as the bars. Instead, we can vary the size of the words themselves to represent the patterns of their use in the text.

Tag cloud exemplifies a broad method that can be called media visualization: creating new visual representations from the actual visual media objects, or their parts. Rather than representing text, images, video or other media through signs such as points or rectangles, media visualizations build new representations out of the original media.

In view of our discussion of the data reduction principle, I am going to refer to this method as direct visualization, or visualization without reduction. Direct visualization takes the existing data and builds visualization out of this data preserving its original form.

Not all direct visualization techniques such as a tag cloud originated in the 21st century. If we project this concept retroactively into history, we can find earlier techniques that use the same principle. For instance, a familiar book index can be understood as a direct visualization technique. Looking at an index, one can quickly see if particular concepts or names are important in this book – they will have more entries than the concepts that take up only a single line in the index.

While both the book index and the tag cloud exemplify the direct visualization method, it is important to consider the differences between them. The older book index technique relied on the typesetting technology used to print the text of the book. Since each typeface was only available in a limited number of sizes, the idea that you can precisely map the frequency of a particular word into its size was counter-intuitive – so it was not invented. In contrast, the tag cloud technique is a typical expression of what we can call 'software thinking' – i.e. the ideas that explore the fundamental capacities of modern software in general, and also its particular areas such as computer graphics. The tag cloud explores the capacities of software to vary every parameter of a representation and to use external data to control it (The data can come from a scientific experiment, from a mathematical simulation, from the body of the person in an interactive installation, etc.). If we take these capacities for granted, the idea to arbitrarily change the size of words based on some information – such as their frequency in a text – is something we may expect to be 'actualized' in the process of cultural evolution (In fact, all contemporary interactive visualization techniques rely on the same two fundamental capacities).

The rapid growth in the number and variety of visualization projects, applications, and web services since the late 1990s was enabled by the advances in computer graphics capacity of PCs including both hardware (processors, RAM, displays) and software (C and Java graphics libraries, Flash, Processing, Flex, Prefuse, etc.) The computer graphics developments both popularized information visualization and also fundamentally changed its identity by foregrounding animation, interactivity and also more complex visualizations that represent connections between many more objects. (As an example, open source data visualization software Mondrian 1.0 running on my 2009 Apple PowerBook laptop with 2.8 Ghz processor and 4 GB of RAM takes approximately 7 seconds to render a scatter plot containing 1 million points.) But along with these three highly visible trends, the same advances also made possible the direct visualization approach – although it has not been given its own name so far.

Direct Visualization: Examples

Cinema Redux was created by interactive designer Brendan Dawes in 2004. The project uses a selection of frames arranged in a grid to reveal the patterns in cinematography and narrative in a number of feature films.

Fig. 11: Cinema Redux: Vertigo, 2004 (www.brendandawes.com)

Dawes wrote a program in Processing that sampled a film at the rate of one frame per second and scaled each frame to 8x6 pixels. The program then arranged these frames in a rectangular grid with every row representing a single minute of the film. Although Dawes could have easily continued this process of sampling and remapping – for instance, representing each frame though its dominant color; instead, he chose to use the actual scaled down stills from the film. The resulting visualization represents a trade-off between the two possible extremes: preserving all the details of the original artifact and abstracting its structure completely. A higher degree of abstraction may make the patterns more visible, but it would also remove the viewer further from the experience of the film. Staying closer to the original artifact preserves the original detail and aesthetic experience, but may not be able to reveal some of the patterns.

What is most important in the context of our discussion are not the particular parameters which Dawes used for *Cinema Redux*, but that he reinterpreted the previous constant of visualization practice as a variable. If previously infovis designers mapped data into new diagrammatic representation consisting from graphical primitives, now it became possible to select any value on the dimension between the data in its original form and its abstract representation. In other words, a designer can now chose to use graphical primitives, or the original images exactly as they are, or any form in between.

Before software, visualization usually involved the two-stage process of first counting, or quantifying data, and then representing the results graphically. Software allows for direct manipulation of the media artifacts without quantifying them. As demonstrated by *Cinema Redux*, these manipulations can make visible the relations between a number of these artifacts. Of course, such visualization without quantification is made possible by the a priori quantification required to turn any analog data into a digital representation. In other words, it is the "reduction" first performed by the digitization process which paradoxically now allows us to visualize the patterns across sets of analog artifacts without reducing them to graphical signs.

Fig. 12: Preservation of Favoured Traces by Ben Fry, 2009 (benfry.com)

For another example of direct visualization, let's turn to Ben Fry's *Preservation of Favoured Traces* from 2009. This web project is an interactive animation of the complete text of Charles Darwin's *Evolution of the Species*. Fry uses different colors to show the changes made by Darwin in each of the six editions of his famous book. As the animation plays, we see the book sentences and passages deleted, inserted and re-written. In contrast to typical animated information visualizations which show some spatial structure constantly changing its shape and size in time reflecting changes in the data (for example, the changing structure of a social network over time), in Fry's project the rectangular shape containing the complete text of Darwin's book always stays the same – what changes is its content. This allows us to see how over time the patterns of the book's additions and revisions become more and more intricate as the changes from all the editions accumulate.

What is also crucial for our discussion is that at any moment in the animation we have access to the complete text of Darwin's book, as opposed to only diagrammatic representation of the changes. At the same time, it can be argued that the *Preservation of Selected Traces* does involve some data reduction. Given the typical resolution of computer monitors and web bandwidth today, Fry was not able to actually show all the actual book text at the same time. – I have created a few visualizations which show a whole book in a single image. To display the whole text of Tolstoy's Anna Karenina in a smallest font which can be read, I had to make the image 14 000 x 6 000 pixels – well beyond the normal screen resolution today.

Fig. 13: AnnaKarenina_string_text_over_rectangles by Lev Manovich, 2009

Instead, in Fry's project sentences are rendered as tiny rectangles in different colors. However, when you mouse over any part of the image, a pop-up window shows the actual text. Because all the text of Darwin's book is easily accessible to the user in this way, I think that this project can be considered a direct visualization.

Finally, let's add one more example – *Listening Post* by Ben Rubin and Mark Hansen from 2001. Normally, this work is considered to be one of the most successful computer-driven installations in the whole history of this genre rather than an example of infovis. *Listening Post* pulls text fragments from online chat rooms in real-time based on various parameters set by the authors and streams them across a display wall made from a few hundred small screens in a six-act looping sequence. Each act uses its own distinct spatial layout to arrange dynamically changing text fragments. For instance, in one act the phrases move across the wall in a wave-like pattern; in another act words appear and disappear in a checkerboard pattern. Each act also has its distinct sound environment driven by the parameters extracted from the same text that is being animated on the wall.

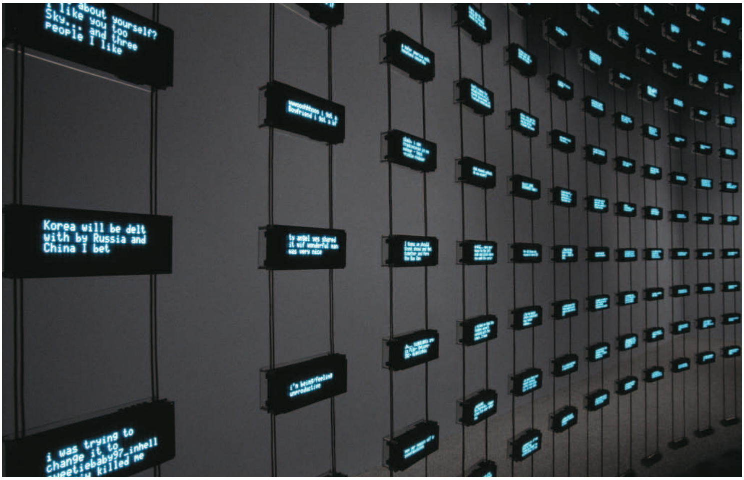

Fig. 14: Listening Post by Ben Rubin and Mark Hansen, 2001 (www.earstudio.com)

One can argue that *Listening Post* is not a visualization because the spatial patterns are pre-arranged by the authors and not driven by the data. This argument makes sense – but I think it is important to keep in mind that while layouts are pre-arranged, the data in these layouts is not. Instead, it is a result of the real-time data mining of the web. So while the text fragments are displayed in pre-defined layouts (wave, checkerboard, etc.), because the content of these fragments is always different, the overall result is also always unique.

Note that if the authors were to represent the text via abstract graphical elements, we would simply end up with the same abstract pattern every time the same act is repeated. But because they show the actual text, which changes all the time, the pattern that emerges inside the same layout is always different.

This is why I consider *Listening Post* to be an example of direct visualization – the patterns it presents depend as much on what all text fragments which appear on the screen wall actually say as on their pre-defined composition. We can find other examples of info projects that similarly flow the data into pre-defined layouts. Manuel Lima identified what he calls a 'syntax' of network visualizations – commonly used layouts such as radial convergence, arc diagrams, radial centralized networks, and others. (To see his taxonomy of network display methods, select "filter by method" on www.visualcomplexity.com/vc/.)

The key difference between most of these network visualizations and *Listening Post* lies in the fact that the former often rely on the existing visualization layout algorithms (and thus implicitly accept the ideologies contained in these) in particular the tendency to represent a network as a highly symmetrical and/or circular structure. The authors of Listening Post wrote their own layout algorithms that allowed them to control the layouts' intended meanings. It is also important that they use six very different layouts that cycle over time. The meaning and aesthetic experience of the work – showing both the infinite diversity of the web and at the same time the existence of many repeating patterns – derive to a significant extent from the temporal contrasts between these layouts. Nine years before Bruno Latour's (2010:159) article where Latour argues that our ability to create "a provisional visualization which can be modified and reversed" allows us to think differently since any "whole" we can construct now is just one of numerous others, and *Listening Post* beautifully staged this new epistemological paradigm enabled by interactive visualization.

The three influential projects I considered demonstrate that in order to highlight patterns in the data we don't have to reduce it by representing data objects via abstract graphical elements. We also don't have to summarize the data as it is common in statistics and statistical graphics (think of histogram which divides data into a number of bins). This does not means that in order to qualify as a "direct visualization" an image has to show all 100% of the original data – every word in a text, every frame in a movie, etc. Out of the three examples I just discussed, only *Preservation of Selected Traces* does this. Both *Cinema Redux* and *Listening Post* do not use all the available data – instead they sample it. The first project samples a feature film at the rate of 1 frame per second; the second project filters the online conversations using set criteria that change from act to act. However, what is crucial is that the elements of these visualizations are not the result of remapping of the data onto some new reduced representation – they are the actual data objects selected from the complete data set. This strategy is related to the traditional rhetorical figure of synecdoche – specifically its particular case where a specific class of thing refers to a larger, more general class. (For example, in *Cinema Redux* one frame stands for a second of a film.)

While sampling is a powerful technique for revealing patterns in the data, *Preservation of Selected Traces* demonstrates that it is also possible to reveal patterns while keeping 100% of the data. But you already have been employing this strategy – if you ever used a magic marker to highlight important parts of a text. Although text highlighting normally is not thought as visualization, we can see that in fact it is an example of 'direct visualization without sampling.'

Cinema Redux and *Preservation of Selected Traces* also break away from the second key principle of traditional visualization – communication of meaning via spatial arrangements of the elements. In both projects, the layout of elements is dictated by the original order of the data – shots in a film, sentences in a book. This is possible and also appropriate because the data they visualize is not the same as the typical data used in infovis. A film or a book is not just a collection of data objects – they are narratives made from these objects (i.e. the data has a sequential order). Although it is certainly possible to create effective visualizations that remap a narrative sequence into a new spatial structure (see, for instance, the gorgeous *Writing Without Words* by Stefanie Posavec or *The Shape of Song* by Martin Wattenberg), *Cinema Redux* and *Preservation of Selected Traces* intentionally preserve the original sequence.

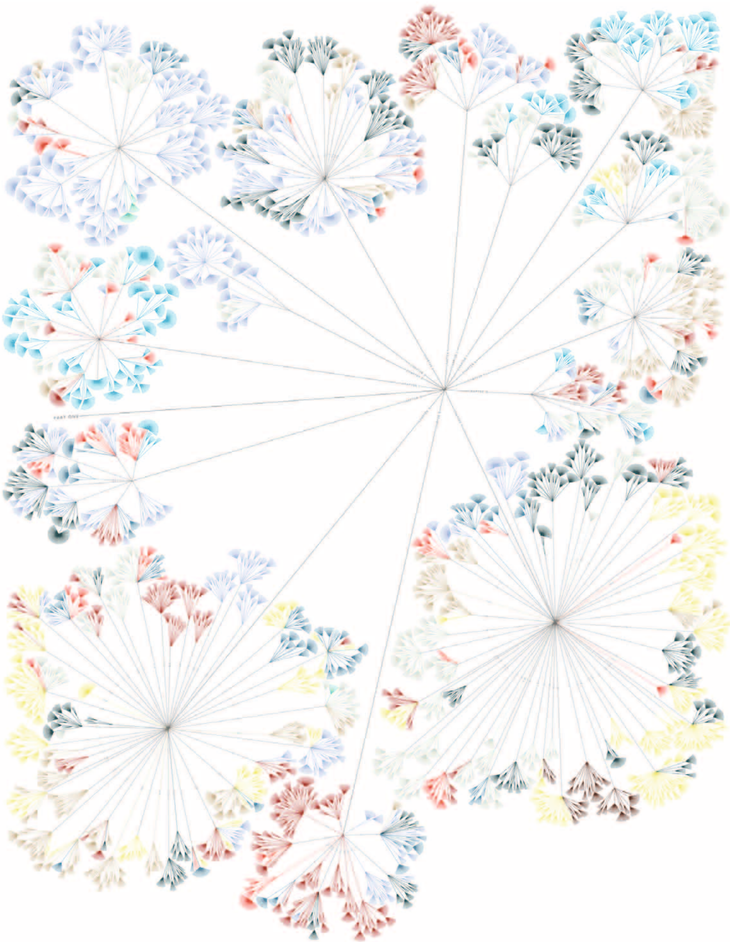

Fig. 15: Writing Without Words by Stefanie Posavec, 2007 (www.itsbeenreal.co.uk)

Fig 16: The Shape of Song (Madonna: "Like a Prayer") by Martin Wattenberg (www.turbulence.org)

Preserving the original order is particularly appropriate in the case of cultural data sets that have a time dimension. We can call such data sets "cultural time series." Whether it is a feature film (*Cinema Redux*), a book (*Preservation of Selected Traces*) or a long Wikipedia article (*History Flow*), the relationships between the individual elements (i.e., film shots, book's sentences) and between larger parts of a work (i.e. film scenes, book's paragraphs and chapters) which are situated in different points in work's timeline are of primary importance to any narrative. While we consciously or unconsciously notice many of these patterns during watching / reading / interacting with the work, projecting time into space – laying out movie frames, book sentences, and magazine pages in a single image – gives us new possibilities to study them. Thus, *space* turns out to play a crucial role in direct visualization after all: it *allows us to see patterns between media elements that are normally separated by time*.

Let me add to this discussion two more examples of direct visualization that my students and I created at *Software Studies Initiative* (lab.softwarestudies.com/2008/09/cultural-analytics.html). Inspired by the artistic projects which pioneered the direct visualization approach as well as by the resolution and real-time capabilities of supervisualization interactive systems such as HIPerSpace (35,840 x 8,000 pixels, 286,720,000 pixels total) developed at Calit2 where our lab is located, my group has been working on techniques and software to allow the interactive exploration of large sets of visual cultural data.

Fig. 17: Supervizualizaiton on HIPerSpace (vis.ucsd.edu)

Some of the visualizations we created use the same strategy as *Cinema Redux* – arranging a large set of images in a rectangular grid. However, having access to a larger resolution display allows us to include all 100% of the data as opposed to using its samples. For example, we created an image showing all 4 553 covers of every issue of Time magazine published between 1923 and 2009. (We also compared the use of images in Science and Popular Science magazines by visualizing all pages of every issue published between 1872 and 1922 in *The Shape of Science* by William Huber, Tara Zapel, and Lev Manovich in 2010).

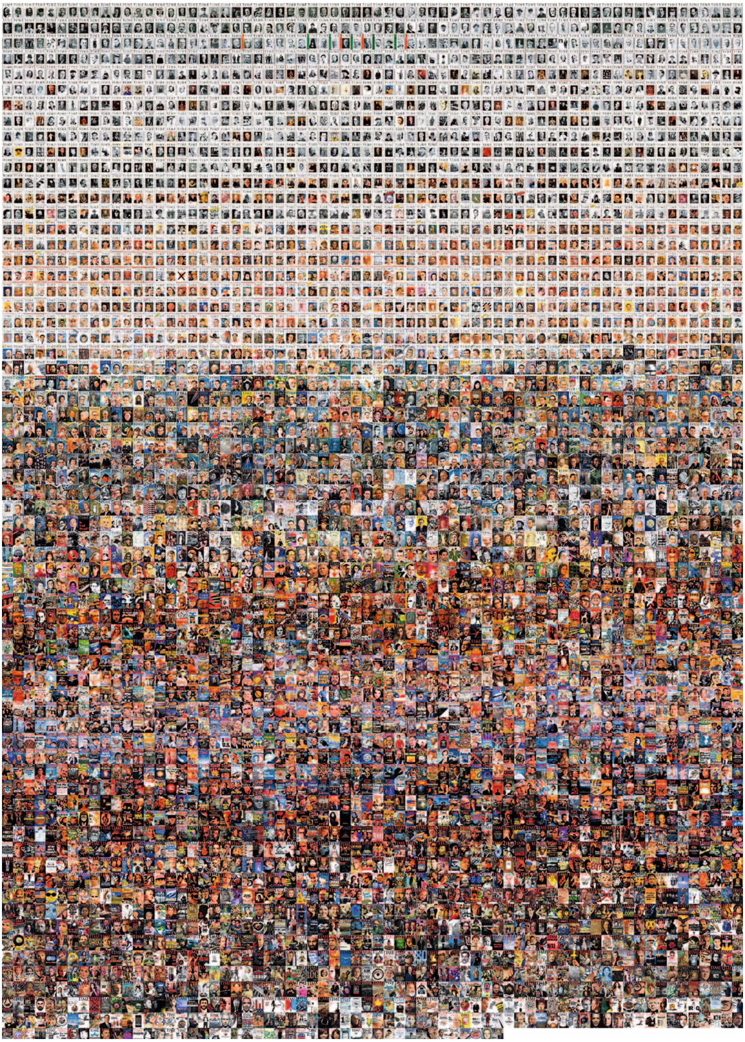

Fig. 18: Time-covers-all by Jeremy Douglass and Lev Manovich, 2009

Cinema Redux and the *Time*-covers visualization (as well as *The Shape of Science*) make equal the values of spatial variables to reveal the patterns in the content, colors, and compositions of the images. All images are displayed at the same size arranged into a rectangular grid according to their original order. However, it is also possible to create direct visualizations where spatial layout communicates additional information. Consider a different visualization of *Time*-covers.

Fig. 19: Time_covers_1923_to_2008, Jeremy Douglass and Lev Manovich, 2009

The horizontal axis still follows the original image sequence: time runs from left to right, and every cover is arranged according to its publication date. This allows us to use the vertical axis to represent new information. In this case, it shows the average saturation (the perceived intensity of colors) of every cover which we measured using computer image analysis.

Such mapping is particularly useful for showing variation in the data over time. We can see how color saturation gradually increases during Time publication, reaching its peak in 1968. The range of all values (i.e., variance) per year of publication also gradually increases – but it reaches its maximum value a little earlier. It is perhaps not surprising to see that the intensity (or "aggressiveness") of mass media as exemplified by Time gradually raises up to the 1970s as manifested by changes in saturation and contrast. What is unexpected, however, is that since the beginning of the 21st century, this trend is reversed: the covers now have less contrast and less saturation.

The strategy used in this visualization is based on the familiar technique – a scatter graph. However, if a normal scatter graph reduces the data displaying each object as a point, we display the data in its original form. The result is new graph type, which is literally made from images – that's why it is appropriate to call it an 'image graph.' (A number of computer scientists have explored a related technique for browsing image collections where a part of a collection is displayed in a similar 'image graph' form (Marchand-Maillet/ Bruno 2006:5). In most of the reported research, images are organized by visual similarity which is calculated via computer image analysis. While this strategy is often useful for the analysis of cultural patterns, in many cases, such as the *Time* cover analysis, we want to see how visual features vary over time. Therefore, we use original metadata – i.e dates of publication – for one axis and measurement of one or more visual features – in this case, saturation – for the second axis.)

What is Visualization?

In an article on the then emerging practice of artistic visualization, I defined visualization as "a transformation of quantified data which is not visual into a visual representation" (Manovich 2002:2) At that time, I wanted to stress that visualization participates in the reduction projects of modern science and modern art, which led to the choice of the article's title: *Data Visualization as New Abstraction and Anti-Sublime*. I think that this emphasis was appropriate given the types of infovis being created at that time (Although I used a somewhat different formulation for the definition that appears in the beginning of the present article – "a remapping from other codes to a visual code" –, the two definitions express the same idea). Most information visualization today continues to employ graphical primitives. However, as the examples we looked at demonstrate, alongside this "mainstream" infovis, we can find another trend – projects where the data being visualized is already visual, such as text, film frames, magazine covers. These projects don't use the reduction typical for infovis from its beginnings in the 18th century until today. They also often break away from the second key principle of infovis – the mapping of the most important dimension in the data into spatial variables.

So does 'direct visualization' actually constitute a form of infovis, or is it a different method altogether? We have two choices. Either we need to accept that this is something new and different, or we can revise our understanding of what infovis is.

Given that all direct visualizations we looked at aim at making patterns and relations in the data visible, this aim certainly aligns them with infovis as it developed during the last 300 years. It is also relevant to note that a number of the most well-known infovis projects of the 2000s – including *Cinema Redux* and *Preservation of Selected Traces* – follow the direct visualization approach. This means that people intuitively identify them as visualizations even though they do not consist of vector elements but of media such as text and images. Similarly, a recent Phrase Net technique developed by Frank van Ham, Martin Wattenberg, and Fernanda Viégas (2009) that was awarded "Best Paper" at *IEEE InfoVis 2009*-conference also operates within a direct visualization paradigm.

Does this mean that what we took to be the core principle of information visualization during its first three centuries – the reduction to graphic primitives – was only a particular historical choice, an artifact of the available graphics technologies? I think so. Similarly, the privileging of spatial variables over other visual parameters may also turn out to be a historically specific strategy, rather than another essential principle of visualization practice. The relatively new abilities brought by computer graphics to control color, transparency, texture, and any other visual parameter of any part of an image allows us to start using these non-spatial parameters to represent the key dimensions of the data. This is already common in scientific and geovisualization – but not yet in information visualization.

Why has infovis continued to rely on computer-generated vector graphics during the 1990s and 2000s when the speed with which computers can render images has been progressively increasing? Perhaps the main factor has been the use of the web as the preferred platform for delivering interactive visualization. The web technologies made it relatively easy to create vector graphics and stream video – but not to render large numbers of continuous tone (i.e., raster) images in real-time. During these decades, this required a graphics workstation, a high-end PC with a special graphics card or a game console with optimized graphics processors. It also took lots of software development. Although video games and 3D-animation programs could render impressive numbers of pixels in real-time, this was achieved by writing code that directly accesses hardware – something that very high-level media programming environments such as Processing and Flash/Flex could not do. However, as processing power and RAM size keep increasing, these differences between platforms and programming environments gradually disappear.

Fig. 20: ImageGraph by Lev Manovich, 2009

For example, the ImageGraph program which I wrote in 2009 using the high-level programming environment *imageJ* (an open source application for image processing commonly used in the sciences), can render a 30 000 x 4 000 pixels image which shows 4 535 Time covers in a few minutes on my Powerbook laptop (processor: 2.8 Ghz Intel Core 2 Duo; memory: 4GB 1067 Mhz DDR3).

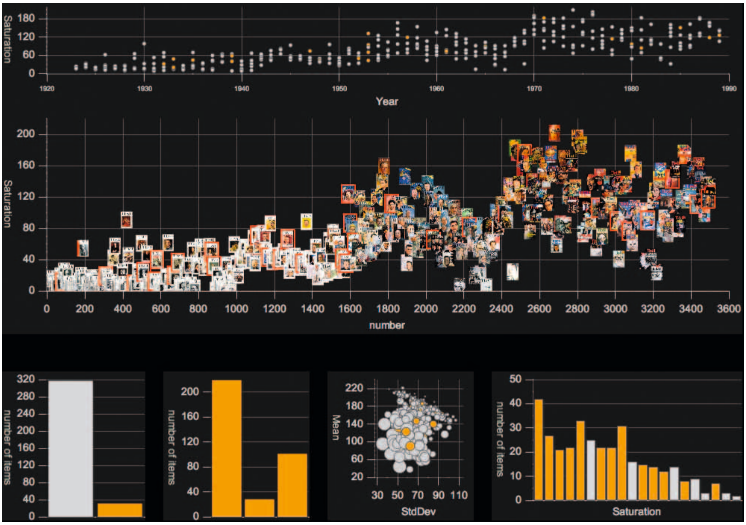

Fig. 21: Cultural analytics chart selection 2 (with VisualeSense) by Lev Manovich, 2010

VisualSense software that we developed in 2009-2010 at National University of Singapore's *Multimodal Analysis Lab* using Flash/Flex allows a user to define a number of graphs and change their positions and sizes. The graphs can use vector primitives (points, circles, rectangles) or they can show the actual images – thus allowing for the interactive construction of direct visualizations if we keep the number of images and their size small.

Finally, the *HiperView* application we developed together with *Calit2 Center of Graphics, Visualization and Virtual Reality* (GRAVITY) takes advantage of the 286 megapixel resolution and significant memory of HIPerSpace to enable interactive manipulation of image graphs which can contain up to 4000 images of *any* size.

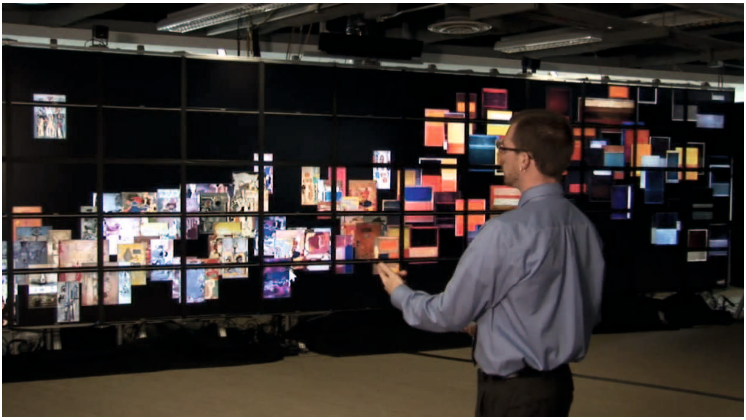

Fig. 22: Mark Rothko Paintings on the 287-Megapixel HIPerSpace-Wall at Calit2, 2009

I believe that direct visualization methods will be particularly important for humanities, media studies and cultural institutions which now are just beginning to discover the use of visualization, but which eventually may adopt it as a basic tool for research, teaching and the exhibition of cultural artifacts – the first conference on visualization in humanities took place at the MIT in May 2010 (hyperstudio.mit.edu/h-digital). Humanists always focused on analyzing and interpreting details of the cultural texts – be they poems, paintings, music compositions, architecture, or, more recently, computer games, generative artworks, and interactive environments. This is one of the key differences between humanities and sciences – at least, as they were practiced until now. The former are interested in particular artifacts (which can be taken to exemplify larger trends); the latter are interested in general laws and models.

If humanists start systematically using visualization for research, teaching and public presentation of cultural artifacts and processes, the ability to show the artifacts in full detail is crucial. Displaying the actual visual media as opposed to representing it by graphical primitives helps the researcher to understand meaning and/or cause behind the pattern they may observe, as well as discover additional patterns. Therefore, creating visualization out of media is not just a nod to humanities tradition – it is an approach to visualization which is perfectly suited to particular methods and data of the humanities, i.e. cultural artifacts, and, more recently, peoples' communication and social activities related to these artifacts happening on social networks.

While graphical reduction will continue to be used, this is no longer the only possible method. The development of digital computers and the progress in their media capacity now makes a new type of visualization possible that I call 'direct visualization' – i.e., visualization without reduction. (It is possible however that our interactive interfaces to visualizations are effective precisely because they do provide certain reduction functions. I am thinking in particular about zoom command. We zoom into direct visualization such as Time covers to examine the details of particular covers. We zoom out to see the overall trends. When we do that, the images are gradually reduced in size, eventually becoming small color dots.)

Acknowledgments

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Biography

Lev Manovich, PhD
Professor at the Visual Arts Department, University of California San Diego, and director of the Software Studies Initiative at California Institute for Telecommunications and Information Technology

Research:
History and Theory of Media, Info-Aesthetics, Navigation in Video Games, Programming

www.manovich.net
manovich@ucsd.edu

Publications:
– *Software Takes Command,* Cambridge/London 2010.
– *Black Box – White Cube,* Berlin 2005.
– *The Language of New Media,* Cambridge/London 2001.